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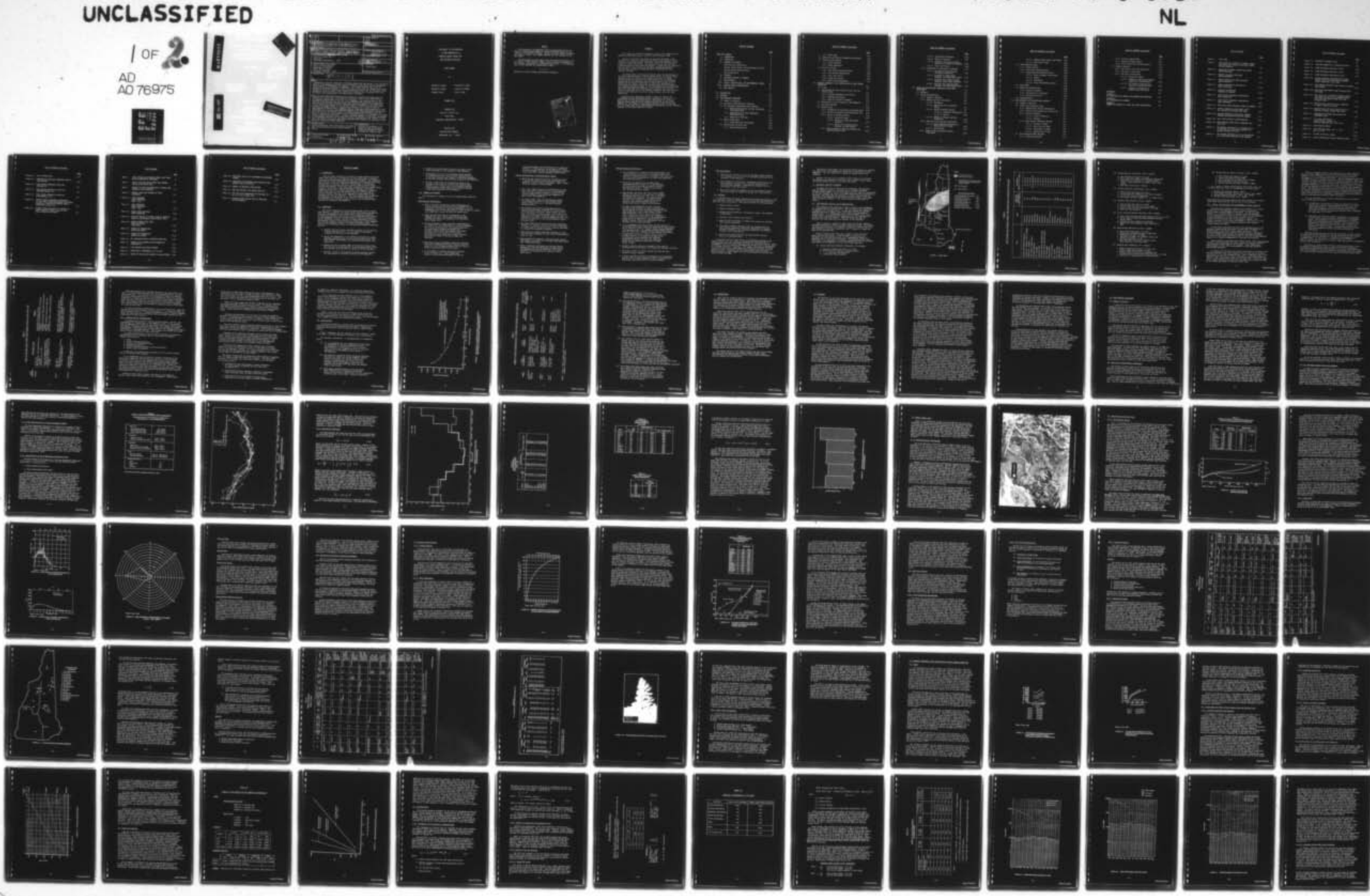

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16. Abstract

A feasibility study was conducted to determine whether the wind energy in the mountainous regions of New Hampshire could be used as a possible energy course for the Portsmouth Naval Shipyard in Portsmouth, New Hampshire. The results indicate that there is adequate wind energy available at mountain sites to drive even the largest wind turbine generators (WT's) now planned, and that many potential sites exist in relatively close proximity to utility lines. Other studies have verified that, in general, WT's can be readily interconnected with existing electric utilities.

Eight specific sites were identified on the basis of available wind speed data, the incidence of severe icing, environmental constraints, plus on-site interpretation of vegetative deformation by the wind (tree flagging). The interpretation of wind deformed vegetation has been found to be cost-effective in estimating average annual wind speed, and therefore long-term wind power potential. Based on the experiences of this study there appears to be a limited number of available WT sites which have sufficient geographic extent to support large clusters (i.e., farms) of WT's of approximately 20-100 MW rating. Clusters such as these have been recommended by other investigators as the most cost-effective approach to WT power generation. Technically, the local utility can "wheel" power to the Naval Shipyard from mountain sites, but doing so would not be cost-effective for the Shipyard because of an abundance of on-site, low-cost cogenerated electricity. A simple near-term approach to wind power development in New Hampshire appears to be through the private exploitation of WT clusters of less than 5 MW capacity on private land. This approach would minimize the regulatory review process by state and federal agencies.

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WIND ENERGY IN THE MOUNTAINS OF NEW HAMPSHIRE AS A POTENTIAL ENERGY SOURCE FOR THE PORTSMOUTH SHIPYARD

FINAL REPORT

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OCTOBER 1979

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FOREWORD

This report was prepared by Arthur D. Little, Inc. under Contract N00014-79-C-0536 with the U.S. Office of Naval Research (ONR).

Because of the short time frame of the study described it was necessary to assemble an experience team which could provide a useful output in a short time frame. Therefore, a case was assembled, which consisted of Arthur D. Little, Inc. employees and Mr. John E. Wade, a meteorologist at Oregon State University. In addition, the consulting services of Mr. Alan A. Smith of the Mount Washington Observatory were procurred to assist in defining local climatology and site specific wind data.

The authors wish to sincerely thank all those who contribution in the study described herein. Special thanks are due to Captain Thomas Stallman of the U.S. Navy for his support throughout the study. Special thanks are also due to Mr. Alan Smith of the Mt. Washington Observatory for his assistance with siting studies, to Ms. Patricia Crawley and the staff of the Arthur D. Little art department, for their help on the final report, Ms. Katinka Csigi for her diligence in obtaining documents and data, to Mr. William Koch for his assistance with field tests and data analyses, to Mr. Lawrence Ochs for his help with wind data, and to Ms. Marianne Brissette, Ms. Linda D'Ercole and Ms. Linda Nazaretian for their diligent support with the typed manuscript.

Numerous other individuals outside of Arthur D. Little, Inc. contributed data and invaluable support essential to the effort. Of special note is the help provided by Mr. Tom Boucher of the Green Mountain Power Corporation, Mr. Raymond Danforth of the Brown Paper Company, Mr. Joel McCall of the National Weather Service in Concord, N.H., Mr. Harry Reed of the Cannon Mountain Corporation, and Dr. Bradford Washburn of the Boston Museum of Science.

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EXECUTIVE SUMMARY

I. INTRODUCTION

With the rapid increase in the costs of energy derived from fossil fuels, there has been a strong drive in the United States to develop alternative energy sources, many of which are renewable. The approaches followed have varied geographically depending on the available resources. Many regions of the U.S., especially the Southwest, have abundant sunlight and are pursuing the use of various forms of solar energy. Northern New England, on the other hand, receives much less annual energy directly from the sun. Wind speed records, however, from coastal anemometer sites and from Mount Washington, New Hampshire (elevation 1917m, 6288 feet), one of the windiest locations in North America clearly indicate that there is an abundance of wind energy in the mountains and near the coastline. This study examines the feasibility of employing the wind energy in the vicinity of Mount Washington, New Hampshire, as a possible energy source for the Portsmouth Naval Shipyard in Portsmouth, New Hampshire.

II. OBJECTIVES

The overall objectives of this four-month study, were to assess wind resource, to evaluate the institutional and technical barriers to wind power development in the region, and to assess the viability of using wind generated electricity for the Portsmouth Naval Shipyard. A prime geographic focus of the wind resource study was originally the Mt. Washington vicinity, but due to siting constraints, the study was expanded to much of the northern and central part of New Hampshire with the main emphasis focused in the Mount Washington region. In carrying out the detailed study, the following task-oriented objectives were to:

- Identify the wind resource potential primarily in the vicinity of Mount Washington, N.H., but not beyond the geographic boundaries of the State of New Hampshire.

- Develop and demonstrate a cost-effective approach for rapidly assessing candidate sites for wind turbines (WT's) that would merit further investigation with long-term measurements with anemometers.

- Examine the cost of energy (COE) and structural design trade-offs inherent in installing WT's at remote mountain sites that may have peak wind velocities in excess of 67 m/s (150 mph).

- Identify, classify, and evaluate WT design features required for installation at preferred locations in New Hampshire.

- Identify the institutional barriers that apply to wind power development in the mountains of New Hampshire.

- Investigate the role of the Portsmouth Naval shipyard as a possible end user of electricity generated by WT's at mountain locations and "wheeled" to the Naval Shipyard by the local utility, Public Service Company of New Hampshire.

- Provide a report which is sufficiently broad in its coverage of the topic yet specific and detailed where required to be of direct use in the on-going formation of New Hampshire energy plans and in follow-on studies of wind power potential in New Hampshire.

III. SUMMARY OF FINDINGS

The following is a summary of the key findings made during the study:

Wind Resource Availability

- Much of the upper elevation on Mount Washington has a wind resource well in excess of that required for the generation of wind power, but Mount Washington is not a recommended site for the installation of WT's because of extreme wind conditions, icing, and land use restrictions.

- Eight specific locations are recommended as good candidate WT sites. These sites were chosen after studying and visiting 23 candidate sites distilled from a larger list.

- The wind resource at many locations in New Hampshire is suitable for the installation of currently available WT's and an interconnection with nearby powerlines. For satisfactory economic performance WT's presently require sites with average wind speeds in excess of 5.4 to 6.3 m/s (12 to 14 mph). Many locations were identified at which an annual wind speed in excess of 8.0 m/s (18 mph) was estimated.

- Additional resource assessment studies are required, after which anemometers and data recorders should be installed at the leading candidate sites in order to derive a long-term record of site winds.

- It is possible to estimate wind power potential at key locations (i.e., wind prospecting) quickly by using aerial photography as well as

on-site measurements and interpretation of vegetative indicators. This approach can be used in the future at other candidate WT sites in New Hampshire to catalog other sites with a greater geographic distribution.

Siting, Institutional, and Environmental Issues

- There are many potential WT sites of sufficient area to install WT clusters capable of generating a few megawatts of power (order 5 megawatts). Many of these sites are located on private lands.

- Due to the rugged terrain and unavailability of land area, there are few good WT sites in New Hampshire that are large enough to support a cluster of wind turbines capable of generating many megawatts of power (order 100 megawatts).

- At present severe land use restrictions prohibit the installation of WT's on most mountain peaks within federal lands (i.e., the White Mountain National Forest).

- The simplest near-term WT siting approach from a legal and institutional viewpoint is to have private parties develop sites with a rated capacity of less than 5 MW outside of federal lands. By so doing, the owners will not require a federal permit, will not be regulated by the Public Utilities Commission (PUC), and will not be required to file an Environmental Impact Statement (EIS).

- The visual impact of WT's and electrical transmission systems (i.e., towers, lines) on the local countryside is a major concern and may provide a serious impediment to siting WT's at specific locations.

- State parks and private land areas represent the best near-term site candidates for WT's from an institutional point of view.

- Many potential WT locations, with high annual average wind speeds, are remote (1 to 5 miles) from access roads and existing powerlines.

- Radio, television, microwave, and aircraft beacon antennas are scattered throughout the mountains of New Hampshire but are not perceived to be a major barrier to the installation of clusters of WT at prime sites.

Machine Design Considerations

- The installation of clusters of WT's spaced within ten rotor diameters of each other on mountain ridges, well-exposed to prevailing winds, is estimated to be one of the most cost effective approaches to large scale generation of electricity by WT's.

- Severe ice accumulation at altitudes above approximately 1070 m (3500 ft.) in New Hampshire can pose a safety problem and severely restrict the operation of WT's. Therefore sites below this altitude should be sought.

- Many present horizontal axis wind turbine (HAWT) designs will have to be strengthened to withstand the higher peak winds (up to 67. m/s or 150 mph) on mountain top locations. The added machine cost for these changes is generally more than offset by the increased energy capture if machines are rated at higher wind velocities.

- For most of New Hampshire WT sites a cluster of medium scale machines of power rating between 200 and 500 kW is a more reasonable approach to wind power generation than a lesser number of MOD-2, 2500 kW machines. Such a choice would allow Such a choice would allow smaller WT components to be transported and erected at the predominantely remote sites, in addition to considerations of aesthetic appeal, land area requirements, and the ultimate cost of energy generated.

- It is recommended that wind turbine cut-out speeds (i.e., wind speeds above which blades are feathered to reduce loads) not be raised in order to increase annual energy production from mountain sites. The minimal increased energy capture does not offset the increased stresses imposed on machines.

- Strengthened versions of present vertical axis wind turbines (VAWT's) of the Darrieus designs should be considered strong candidates for mountain installations because of their high rated wind speeds and the perceived potential for simple design changes.

- Readily available electrical equipment can be used to synchronize and interconnect a WT output with electric utilities.

- The safety of WT's to utility workers has thus far been assured by proper designs.

- A single candidate WT should be installed on one accessible peak in order to obtain hardware as well as operation and maintenance experience before installing clusters.

User Requirements

- There is not a strong role for the Portsmouth Naval Shipyard in Portsmouth, N.H., as a user of wind power generated in the mountains of New Hampshire.

- The extensive use of low-cost cogenerated electricity by the Naval Shipyard, combined with a planned installation of new generating equipment, eliminates the shipyard role in wind energy in the near future.

- The utility regulatory framework for WT installations favors a third party owner as opposed to the Navy or a local utility.

IV. APPROACH

A straightforward and simple approach was developed and applied in this study whereby a number of potential WT sites were found which exhibited good wind resource potential. The method involved the following steps:

- Examine weather records

- Examine topographic maps

- Examine land availability, restrictions, access, and proximity to powerlines

- Interview local residents and observers

- Employ aerial photography to examine site access and evaluate wind deformed vegetation

- Visit most promising candidate sites for interpretation of wind deformed vegetative indicators, measurement of surface roughness parameters, and preparing estimates of suitability of sites for WT installation.

- Estimate wind power potential and qualitatively rank key sites after analyzing data.

In parallel with the above effort, an examination was made of the legal, institutional and regulatory framework for installing WT's at New Hampshire sites and interconnecting them with the local utility. Where information from this exercise influenced the siting work, it was factored in to change direction or emphasis. For example, the extreme conditions and land restrictions on Mount Washington channeled the effort to other peaks very soon. Similarly, the land restrictions within the White Mountain National Forest (WMNF) very soon necessitated the parallel site search outside the WMNF.

The specific requirements and operating characteristics of existing and planned WT's were examined as candidates for installation in New Hampshire. The cost trade-offs in design and energy capture were examined.

Finally, the role of the Portsmouth Naval Shipyard in Portsmouth, New Hampshire, was examined by looking at their present energy usage, electricity generation mix, costs and future plans.

V. GEOGRAPHIC REGION OF INTEREST

Initially the study focused on Mount Washington, New Hampshire, and the immediate vicinity, including all of the White Mountain National Forest (WMNF). It was soon discovered that land use restrictions at the best candidate WT sites in the WMNF prohibited their installation. Therefore, the study area was expanded to include a good portion of the state of New Hampshire, while retaining prime interest in the WMNF region as shown in Figure 1. The sites studied are also shown in Figure 1.

VI. WIND RESOURCE (Results and Recommendations)

The candidate sites indicated by dots in Figure 1 are recommended for various levels of further study. They are specifically identified in Appendix B of the main report. During this program the approach described provided a number of key sites which look promising for further study. It is recommended that a limited number of key sites listed below be instrumented with anemometers for the acquisition of accurate long term wind records. Numerical models can then be developed for some prevailing flow patterns in the mountains.

Table 1 contains a summary of these sites and the key vegetative indicators employed to infer the annual average wind speed. The details are described in Chapter 3 and Appendix B wherein it is shown that the wind characteristics (shear, gustiness, etc.) on many N.H. peaks are good for WT installations.

Table 1 indicates that there are a number of sites with good annual average wind speeds. A limited number of the sites are accessible to roads and powerlines, but the geographic extent of available land at each site is uncertain. The following prime sites from Table 1 are recommended for further consideration and the possible installation of anemometers to verify wind energy potential.

(1) Artists Bluff/Bald Mountain (Franconia, 735 m height)

- Excellent average wind speed (~8.4 m/s)
- Private land at outflow of Franconia Notch
- ~1 km from roads and powerlines
- Limited land area available

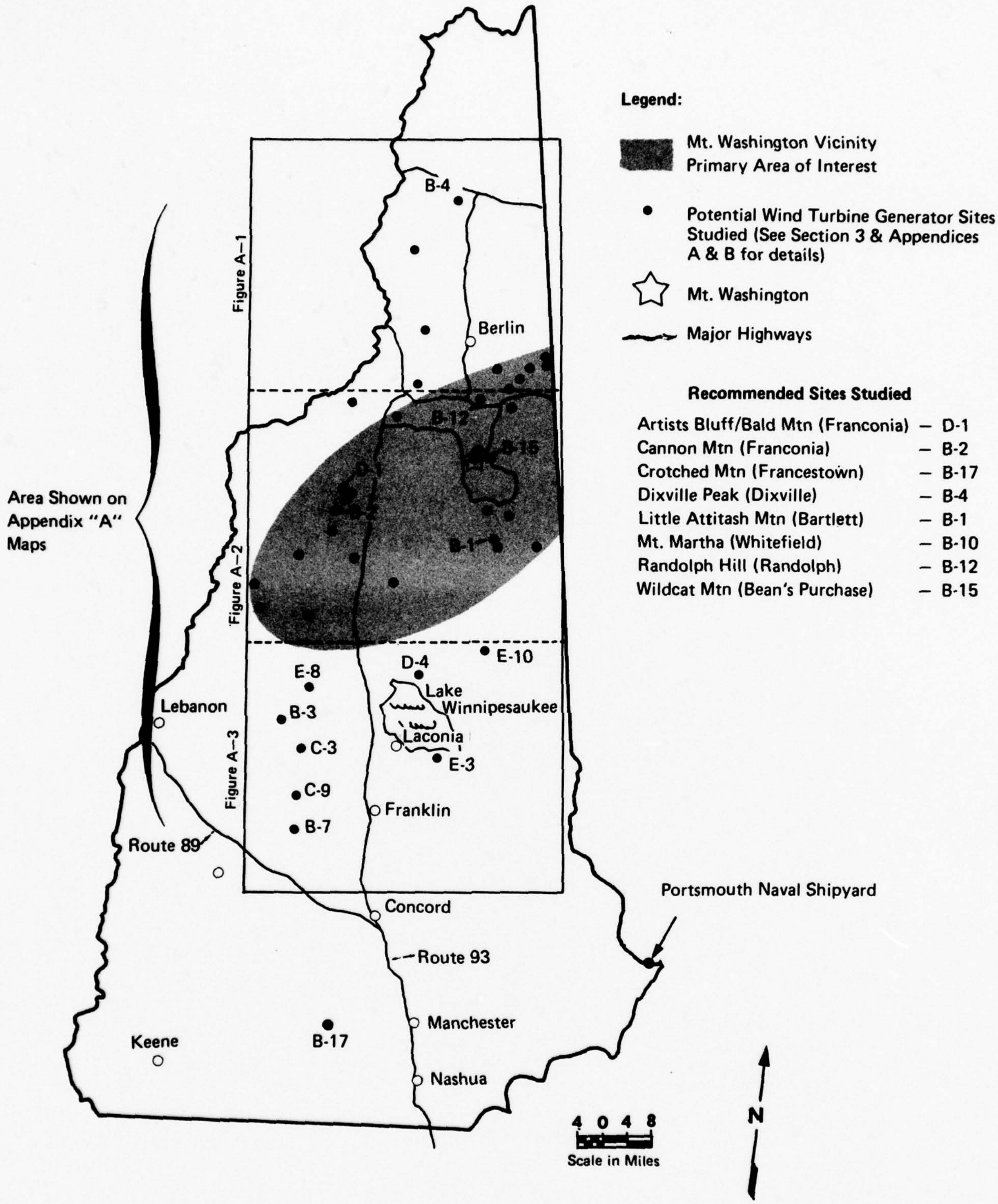


FIGURE 1 STUDY AREA

Table 1

SITES STUDIED AND ESTIMATED ANNUAL WIND SPEED BASED ON VEGETATIVE INDICATORS

SITE	TOWN	INDICATED PREVAILING WIND DIRECTION	ESTIMATED ANNUAL $\overline{V}$, m/s (mph)
Artists Bluff/Bald Mountain	Franconia	SE	8.4 (18.8)
Cannon Mt. (Central Part of Range)	Franconia	SE	8.1 (18.1)
Cannon Mt. (Summit)	Franconia	SE	6.2 (13.9)
Gap Between Cannon Balls	Franconia	SSE	Not Determined
Crotched Mountain	Francestown	WNW	8.1 (18.1)
Mt. Cardigan	Alexandria	NW	7.4 (16.6)
Dixville Peak	Dixville	NW	7.3 (17.3)
Franconia Notch (Northwest End)	Franconia	SE	5.0 (11.2)
Franconia Notch (Artists Bluff)	Franconia	SE	8.4 (18.8)
Mt. Kearsarge	Wilmot	NW	6.2 (13.9)
North Kinsman	North Woodstock	SE	8.7 (19.5)
Little Attitash	Bartlett	W	8.1 (18.1)
Mt. Martha	Whitefield	ESE	7.4 (16.6)
Pine Mountain	Gorham	WNW	7.4 (16.6)
Randolph Hill	Randolph	NW	5.5 (12.3)
Mt. Success	Berlin	NW	8.7 (19.5)
Mt. Success (Outlook)	Berlin	SE	8.9 (19.9)
Mt. Washington (The Horn)	Sargent's Purchase	NW	10.7 (23.9)
Wildcat Mountain	Bean's Purchase	NW	8.1 (18.1)

(2) Cannon Mountain (Franconia, 1240 m. height)

- Good average wind speed (~8.1 m/s)
- State Park with tramway for skiing and sightseeing
- Good summit accessibility via tramway and ski slopes. Small powerline to summit, larger lines nearby.
- Land area extent may be limited.

(3) Crotched Mountain (Francestown, 627 m. height)

- Good average wind speed (~8.1 m/s)
- Private land with abandoned fire tower on summit.
- 1-2 km from roads and powerlines
- Fair amount of land available (~2 or 3 MOD-2 WT's)

(4) Dixville Peak (Dixville, 1061 m. height)

- Good average wind speed (~7.3 m/s)
- Private land with ski lift to near summit
- Close to jeep road and powerline at ski slope
- Good land area available

(5) Little Attitash Mountain (Bartlett, 768 m. height)

- Fair to good average wind speed indicated (5.5 to 8.1 m/s)
- Private ski area bordering White Mountain National Forest (WMNF)
- Adjacent to major highway and powerline
- Limited land area available along ridge due to WMNF

(6) Mount Martha (Whitefield, 1219 m. height)

- Good average wind speed (~7.4 m/s)
- Within less restricted portion to WMNF with abandoned fire tower on summit
- Jeep road to summit, but somewhat remote from existing powerlines (~4 km)
- Fair land area potentially available along Cherry Mountain, all within WMNF

(7) Randolph Hill (Randolph, 457 m. height)

- Modest average wind speeds (~5.5 m/s), but suspect higher winds further to west
- Private land with excellent accessibility by existing roads and near major powerline (i.e., ~1-2 km)
- Potential for large quantity of land available

(8) Wildcat Mountain (Bean's Purchase, 1219 m. height)

- Good average wind speed (~8.1 m/s)
- Private ski slope bordering WMNF
- Good accessibility to summit via ski slopes.
- Near powerlines servicing mountain.
- Limited land area available outside of WMNF.

As a result of limited investigation during this study, the following additional sites are recommended for further study:

- Croydon Peak (Croydon, 848 m. height)
- Pliny Range Mountains (Gorham, up to 1070 m. max. height)
- Ossipee Mountains (Ossipee, ~850 m. max. height)
- Red Hill (Moultonborough, 619 m. height)

These additional sites were examined by light aircraft or by remote observation using binoculars and are felt to be promising.

VII. SITING, INSTITUTIONAL, AND ENVIRONMENTAL ISSUES (Results)

The questions of siting a single WT or a cluster (i.e., farm) of many WT's in New Hampshire will be strongly influenced by institutional and environmental constraints. In general there appears to be a limited amount of suitable land area available for the installation of large WT clusters (order 20-100 megawatts). A small percentage of the land is not suitable because of potential WT interference with electromagnetic signals. The primary constraint to WT cluster development is the lack of a broad expanse of a flat or gently-sloping topography which exhibits a good average wind speed.

In the rural, mountainous setting of New Hampshire many of the potential institutional constraints to wind power development in a general sense do not apply or have reduced relevance. Thus, zoning, building, safety, and housing codes are virtually irrelevant or can be handled by application of standard operating procedures. The issue of wind rights and obstructions to wind flow in New Hampshire appears to be readily accommodated by judicious site planning.

Issues related to potential wind turbine owners, their organizational structure, their financing, and their relation to existing utilities and regulatory bodies remain to be resolved. State regulations, however, appear to have laid the groundwork to encourage potential wind turbine operators.

It appears that siting of wind turbine generators in locations which are most favorable from a wind resource point of view may be severely constrained due to other considerations. Table 2 summarizes some of the important laws under which siting considerations take place within the federal, state, and private sectors of the study area. Within the study area, a major portion of the land with favorable wind resources is held by the federal government as national forest land.

Land use constraints within the boundaries of the White Mountain National Forest (WMNF) constitute the most formidable institutional barrier to the development of wind power in the vicinity of Mount Washington (i.e., in the White Mountains). Existing management plans for the WMNF have placed substantially all the land at elevations higher than 2,500 feet in restricted areas--either in Management Areas III (no utility corridors allowed) or IV (no utility corridors or antennas allowed); or designated Wilderness; or Special Areas (e.g., Scenic Areas); or in RARE II areas recommended for Wilderness or Further Planning (see Appendix A maps). The planning process which has led to these designations is based on authority delegated to the Forest Service by Congress over many years. The process incorporates a significant amount of input from the general public and results in the development of management plans which guide all land use and permitting decisions within the forest.

The restrictiveness of the land use designations in the national forest result from two factors:

1) The WMNF has a long history of heavy recreational use which draws widely from the major population centers in the northeastern United States. Aesthetics and the perception of undisturbed remoteness are of incalculable value to these users and the statutes governing the national forest recognize the importance of this use.

2) Wind power has never been formally recognized as a renewable resource under existing statutes, regulations, and management plans. This oversight excludes wind generation of electric power from consideration as a legitimate land use within the multiple-use, sustained-yield context. Also, because of the failure to recognize the wind as a resource, it cannot be considered in the same light as mineral extraction activities which are excluded by statute from certain restrictive regulations.

Existing federal land use controls may be altered in light of newly perceived public needs and desires, but the time frame for such changes is uncertain, and the procedures to accomplish such change are not straightforward. At this point, it appears that wind development on private (and perhaps also on state owned land) could be accomplished without such constraints.

The effort to revise federal land use controls would have to focus on obtaining Congressional action to amend the enabling legislation (including the Multiple-Use Sustained-Yield Act) so as to establish wind power as a recognized "resource" amenable to management under the multiple-use sustained-yield concepts which are applied to national forest lands.

Table 2

SOME OF THE LAWS WHICH AFFECT WIND TURBINE SITING IN THE STUDY AREA

Land Category	Applicable Laws	Comment
Federal	- 16 USC 471	Establishes National Forests
	- Multiple-Use, Sustained-Yield Act of 1964	Guidelines for Allowable Use of National Forest
	- Wilderness Act of 1964	Establishes National Wilderness Preservation System
	- Forest and Rangeland Renewable Resources Planning Act of 1974	Specifies Planning Process for National Forests
	- National Environmental Policy Act of 1969	Environmental Impact Statement Requirements
State	- RSA 162 F	Bulk Power Supply Facility Siting Law
	- RSA 162 H	Energy Facility Evaluation and Siting Law
	- National Environmental Policy Act of 1969 (if applicable)	Environmental Impact Statement Maybe Required if Federal Permit Required
Private	- Zoning Bylaws	Limited Applicability in New Hampshire
	- National Environmental Policy Act of 1969 (if applicable)	Environmental Impact Statement Maybe Required if Federal Permit Required

Even after amending the enabling legislation, the path would not be clear to utilizing high elevation sites in the national forest for wind power generation. It would have to be recognized through the planning and public participation process (or by Presidential fiat) that aesthetic alterations of sensitive areas for the purpose of wind energy development would best serve the needs of the people of the United States. Presumably, these changes would then be incorporated in the Forest Management Plan, enabling Forest Service personnel to authorize such use of the land on a case by case basis.

In view of the above considerations, it is recommended that, under the present institutional framework, private lands or state lands be sought for the installation of WT's. As federal regulations change to reflect changing values and land needs, much additional land may become available for the installation of wind turbines

VIII. MACHINE DESIGN CONSIDERATIONS

An examination was made of existing machine designs, controls, and requirements for installations at New Hampshire sites. It was assumed that New Hampshire sites would be more remote, have higher annual average wind speeds, and higher peak wind speeds than most existing or planned installations. Wind speed data from the summit of Mt. Washington was used as a benchmark in performing analyses. Where needed, wind speeds were scaled down to reflect conditions at lower elevations.

An examination was made of the role of the following site-specific considerations and an assessment made of their effect on machine design characteristics:

- Icing
- Access roads and powerlines
- Operation and Maintenance Costs
- Lightning protection
- Utility Interface Equipment and Personal Safety
- Utility grid interactions

In addition, the operating and maintenance (O & M) costs as remote sites of WT clusters were examined.

It is recommended that site-specific studies be conducted in the future that compare the annual energy capture from a fully developed WT cluster to the costs for the machines, land, access roads, power lines, and other levelized costs before firm siting decisions are made. Early in any such future program it is recommended that a single WT prototype, exhibiting a high rated wind speed (~12.-13. m/s), be installed and tested in order to obtain firm performance and operating data. A few privately developed WT's with the required characteristics are presently being marketed at reasonable costs.

Because of heavy icing at higher elevations in New Hampshire, specific sites below 1070 m (3500 ft.) are recommended. Access roads

do not exist to many prime candidate WT sites in New Hampshire. The additional costs for roads (~ $5,000 per mile) would generally be small part of the total cost for installing megawatt-scale WT clusters. This is true as long as the roads are of low quality and of the order of a few miles (< 5) in length over modest terrain.

Power line costs range from $25,000 to $100,000 per mile depending on voltage and power ratings as well as terrain. An average cost of approximately $40,000 per mile is assumed by local utility personnel. This cost dictates that WT cluster sites be found near existing power lines. Access roads can be combined with power lines to remote sites.

Operation and maintenance (O & M) costs for remote New Hampshire WT sites were estimated to be slightly in excess of those assumed in other sutdies. A levelized annual O & M cost of between 2.6 and 3.0 percent of the installed cost was calculated. This cost was found to have a minor impact on WT installation costs.

Most WT's normally require adequate lightning protection in their designs. There will, however, be additional installation complexities and costs associated with WT installations on solid rock. The associated increased costs are not believed to pose a substantial a barrier to N.H. WT installations.

Standard utility interface equipment, used to assure the proper tie-in of WT's to a utility grid, is available and not a severe cost item. Studies have been and are being conducted to assure the safety of utility personnel working on lines near WT installations. The problems when larger numbers of dispersed WT's are interconnected with utilities are now under study through federal contracts.

Utility grid WT interaction studies indicate that no problem exists as long as the penetration of WT's is very small and closely tied to the main grid. However, test data on analyses do not now exist for the case when WT penetration is a large percentage of the utility total demand or installed on a remote feeder.

The effect of modifying the design and control aspects of existing WT's for higher average wind speeds was examined. The study looked primarily at horizontal axis wind turbine (HAWT's), and addressed the following points:

- Increasing WT rated wind speeds by either increasing the rated power or decreasing the rotor disc area of specific WT's.

- Increasing the machine component strengths to accommodate higher operating loads and higher peak wind speeds.

- Increasing the WT cut-out speeds to capture wind energy above the cut-out speeds of present DOE/NASA WT's.

In addition to federally funded WT's, a few existing commercially available machines were examined and their applicability discussed.

It was found that for many candidate sites in New Hampshire most existing DOE/NASA WT concepts and designs are not optimally sized. It is recommended that for sites with annual average wind speeds in excess of 8 m/s (18 mph), the rated wind speed on the DOE/NASA MOD-X and MOD-2 designs be increased by a suitable combination of decreasing the rotor disc area and increasing the rated wind speed. Component strengths should also be increased to accommodate the peak wind speeds on New Hampshire mountains which are in excess of the normal survival speed, 55.8 m/s (125 mph).

Figure 2 indicates the trend in WT machine costs per kW as a function of site average wind speed for a MOD-2 WT with disc area and power rating modified for minimum machine costs. The cost-of-energy (i.e., ¢/kWh) also follows the trend down in Figure 2.

IX. USER ANALYSIS

The options available to various types of WT owners were explored along with those of the Portsmouth Naval Shipyard. Emphasis was placed on how different owners justify the cost of a wind turbine cluster.

Table 3 summarizes the user analysis for three different classes of WT owner - the Naval Shipyard, the Utility, and a third party.

The findings, conclusions, and recommendations are summarized below:

(1) It is recommended that if a demonstration wind project is implemented in the Mount Washington vicinity, it be developed by a "third party," or by a utility. This study does not recommend any role for the Naval Shipyard in the development of wind energy in New Hampshire.

(2) The regulatory framework (Public Utilities Regulatory Policies Act, PURPA, and the New Hampshire Limited Electrical Producers Act) favors a third party venture by assuring that the utility will be a customer, and by establishing a price for wind generated electricity which may exceed the marginal value to the utility.

(3) Wind energy supplied directly to the Portsmouth Naval Shipyard is not economically attractive because it will have to compete with low cost cogenerated electricity most of the time. Shipyard cogenerated

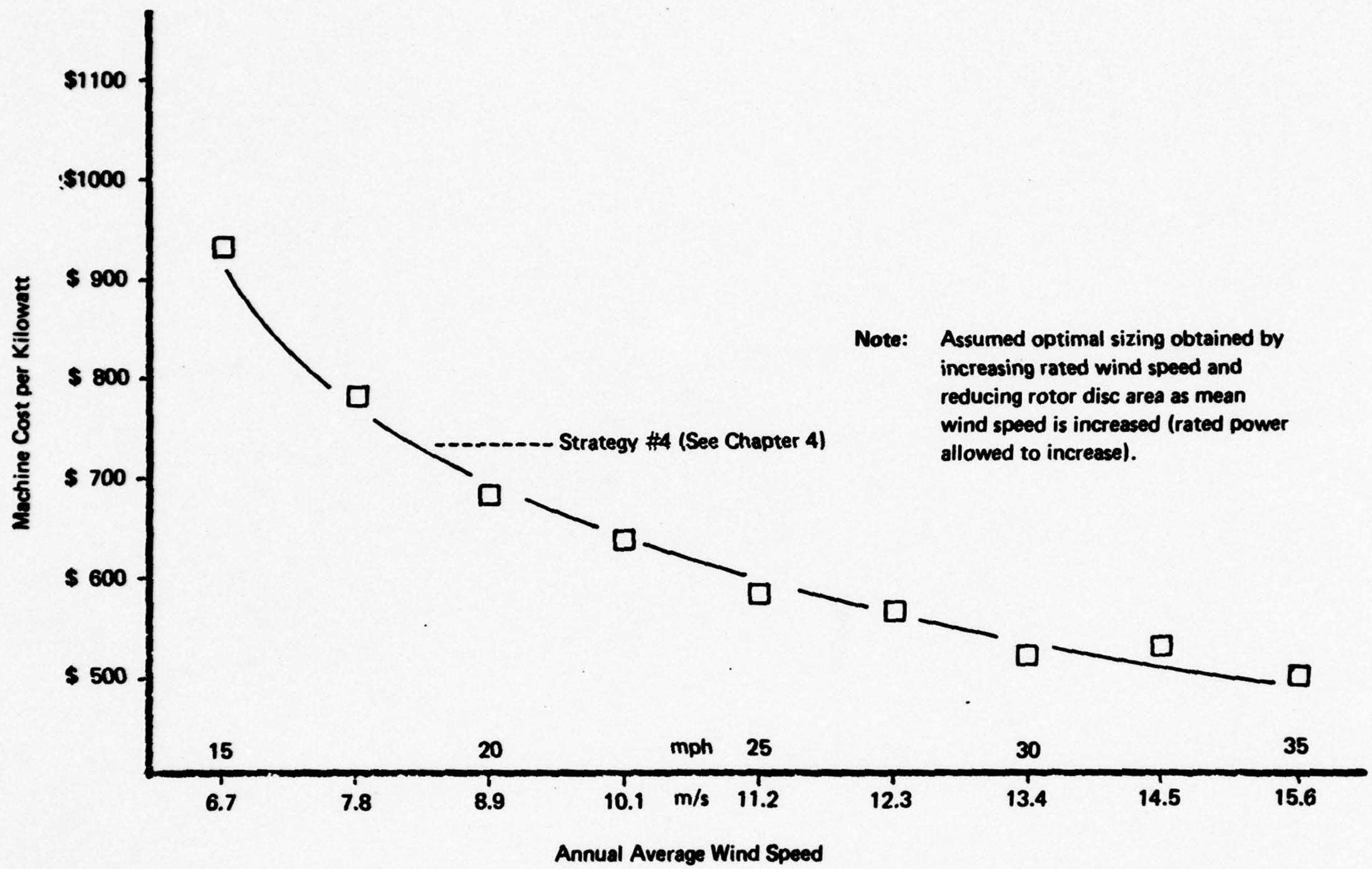


FIGURE 2 COST PER KW AS A FUNCTION OF ANNUAL AVERAGE WIND SPEED FOR OPTIMALLY SIZED MOD-2 WIND TURBINE GENERATOR

Table 3

SUMMARY OF MAJOR CONSIDERATIONS IN OWNING WIND TURBINES IN NEW HAMPSHIRE

OWNER	BASIS FOR BENEFITS	MAJOR PROBLEMS	ROLE OF NAVY	ECONOMIC ATTRACTIVENESS	VALUE OF MOD-2 AT 14 mph/3% FUEL ESCALATION* ($/kW)
Portsmouth Naval Shipyard	Direct fuel displacement in cogeneration.	Minimum opportunity to displace fuel or utility supplied power. Voltage regulation. Complex wheeling issue.	Owns and operated facility.	Very little if any.	$ 500.
Utility (PNH)	Direct fuel displacement in equipment dispatch.	Reluctance to innvoate risky new technology.	No role.	Promising us a demonstration.	$1100.
Third Party	Price fixed by the PUC.	Project financing. Relationship to utility.	Possible role as remote customer.	May be made economically attractive to the investor if value is above installed cost.	$1320

*NOTE: Value of MOD-2 compares with $1350/kW installed cost estimate. If value exceeds costs, project appears economically viable.

energy is generated at a heat rate of 5,000 BTU/kWh compared to a local utility heat rate of 11,000 BTU/kWh (based on generation data reported by each party).

(5) Wind energy wheeled to the Naval Shipyard from the Mt. Washington vicinity is assured by PURPA and can be accomplished at a very modest cost (approximately .1¢/kWh), although there may be a jurisdictional dispute arising from the face that the shipyard is in Kittery, Maine. However, wheeling is not practical because wheeled power cannot be more economical for the Shipyard than direct wind power (see (3) above). Additionally, part of the Shipyard's load is used for submarine testing at 440V, ± 10 volts. The utility voltage variation is considered to be too large to meet this requirement. Therefore, the Shipyard could never rely fully on wheeled power.

(6) High quantities of wheeled power would have the effect of increasing the Shipyard draw on the utility. At present the submarine cable, which feeds power to the Navy Yard, is old and limited in load carrying ability. This cable would require replacement if large scale power wheeling were employed.

(4) The breakeven cost of a wind project depends on several factors; the machine characteristics, the average wind speed at the site, the unit quantity of fuel displaced per kWh generated, the price of the fuel, the fuel escalation rate over the life of the project, the tax structure of the owner, the annual operating and maintenance cost, and the discount rate for capital. If the breakeven value exceeds the installed cost, the project is economically justified. Table 3 indicates that for a third party the value of a MOD-2, 2500 kW WT at a 6.3 m/s (14 mph) site is $1320/kW compared to a second unit WT installed cost estimate of $1350/kW. As costs for mass-produced WT's drop, their installed cost may be less than the value of the electricity generated, at which time they are economically justified.

(7) All things being equal except user mode, the third party option is the most promising economically (see last column of Table 3), because it is expected that the PUC will set a price of at least 4¢/kWh for electricity generated by WT's. This price will be paid by the utility, to be increased annually as the costs of electricity generated by conventional fuels increased.

1.0 INTRODUCTION

Since the oil crisis of 1973-74, increasing and widespread interest has been taken in the possibilities of using the wind as a source of electric energy in the United States. Many private and Government-sponsored organizations have become interested in wind energy because of the depletion of the stocks of fossil fuels, the rapidly increasing costs of existing methods of generating electricity and the political dangers of not being self-sufficient in energy resources.

Electricity plays a major role in providing power for the industrial, agricultural and daily consumer needs of the United States. During the past decade renewed interest has been taken in all the possible sources of energy from which electricity can be produced. Coal, oil and natural gas are being consumed at an alarming rate. Hydro power is being exploited wherever it is economical to do so. Tremendous efforts to apply nuclear energy safely for power production are also being pursued. The potential of inexhaustible sources of energy such as wind, solar radiation, biomass, and geothermal heat are being seriously considered. They each possess unique advantages and can serve very useful purposes in many regions of the United States.

This report describes the technical and economic questions which arise when attempts are made to harness wind energy on a large scale in the state of New Hampshire. The report also outlines the steps to be taken to provide answers to these questions and provides a summary of the results of the first steps in a wind turbine siting study aimed as examining feasibility. In addition, an account is given of past research and development work in Vermont and New Hampshire that forms a basis for some of the work in this study. Wherever possible, hardware design and test experiences as well as study results from ongoing federal and private efforts were employed.

The subject matter can be roughly divided into four parts dealing with wind characteristics, wind turbine hardware design, legal, institutional, and enviornmental barriers to wind power development, and the economic use of wind power.

2.0 APPROACH

The objective of the study discussed in this report was to assist the U.S. Navy in investigating the feasibility of employing wind power in the Mount Washington area of New Hampshire as a possible energy source for the Portsmouth Naval Shipyard. In carrying out the study, all major barriers to the installation of wind turbines were examined. These included an assessment of the available wind power resource based on climatological data and estimates of terrain effects. An appraisal of the physical and institutional barriers that obtain in the region was also made. Additionally, an estimate was made of the technical problems surrounding WT's that may arise due to prevailing site conditions. Lastly an assessment was made of the additional requirements incumbent on the U.S. Navy in order to employ, maintain and service a wind turbine facility. During this study full advantage was taken of the results of studies and tests conducted by the Federal Wind Energy Program.

In order to meet the requirements of the study, the approach outlined below was followed. Each task was addressed nearly in parallel in order to meet the required schedule. For the same reason, a team was formed which broadened Arthur D. Little's capabilities. This team included a climatologist who has researched and published extensively in the area of wind flagged vegetation as an indicator of dominant wind speed and direction. Additionally, the services of a climatological consultant were obtained which proved invaluable for insight into issues unique to Mount Washington, and the White Mountain National Forest Region of New Hampshire.

A large portion of the study focused on developing an assessment of the wind energy resource in the vicinity of Mount Washington. For over a 100 years regular meteorological observations have been made on Mount Washington. With few exceptions the weather records are reputed to be among the most complete in New England. Copies of these wind records for the last ten years were obtained from the National Climatic Center in Ashville, North Carolina. These data were subsequently screened for quality, completeness and representativeness; and the five best years of data used in developing wind power estimates. These results were augmented, where appropriate, with the results of earlier investigators.

It was recognized early in the study that Mount Washington would be difficult to use as a site for wind turbines due to its high incidence of severe weather conditions and restrictions on land use. Therefore, the scope of the study was expanded to include good sites outside the immediate vicinity of Mount Washington and the White Mountain National Forest. In the data sparse regions of northern New Hampshire recourse was made to a variety of remote observation and inferential techniques. Examination of topographic and raised relief maps provided important insights into potentially "fertile" wind turbine sites. Where possible, first impressions from this step

were checked by interviewing local residents, observers, pilots, and other weather conscious individuals for their opinions and recommendations. In conjunction with this, various aerial photographic imageries were considered for their possible survey value. Out of this developed a technique which proved most useful in rapidly and effectively studying the vast land area of central and northern New Hampshire. Photographic reconnaissance using light fixed wing aircraft proved nearly ideal for identifying the presence of wind-deformed vegetation and eolian land features. This technique was equally useful in quickly assessing land availability, exposure to prevailing winds, access, and proximity to power lines. On-site visits to the most promising sites for interpretation of vegetation indicators, measurement of surface roughness parameters and estimates of suitability of sites for WT installation rounded out the resource assessment phase of the program.

In conjunction with the above effort, an examination was made of the legal, institutional and regulatory framework for installing WT's and interconnecting them with local utilities. The issues surrounding the environmental, social and legal aspects of WT installations received close attention. For example, it was soon recognized that potential objections based on visual blight or degradation of the beauty of the landscape will require careful assessment. Also, the scarring effect of the actual WT construction process on the local ecology will have to be considered. Any planned installation will receive close scrutiny by such environmentally aware groups as the Appalachian Mountain Club which is very active in the area. All of these issues and more, will have to be carefully addressed in future more detailed siting studies. The study described herein points out the key issues to be addressed in such a statement and provides initial guidance where possible.

A parallel effort examined the effect of site locations, lightning and prevailing weather conditions on both the design and performance of wind turbines. Generally, environmental conditions in the mountains of New Hampshire are not conducive to the survival of equipment. Storms in the mountains are typically more devastating than those at lower elevations. Ice,lightning, and high winds all can render a WT inoperative. To resist these elements, various components of a WT require strengthening or modification. The greatest threat of damage arises from the high winds--on average, an appropriate maximum anticipated wind speed at a site is seven times the annual average speed. Therefore, the same high annual average wind speed that encourages mountain installations necessitates increasing the strength and hence the cost of WT's. As a first step in the analysis, various possible WT designs and operating strategies were identified. To the maximum extent possible use was made of NASA/DOE WT design studies and experience. The approach adopted considered only changes in existing designs that would be required for them to be usable. Changes in the costs of structural elements were derived from studying the implications of life limiting stresses on key components. Changes in the cost of

the generator and drive train were estimated from published price data, augmented by telephone interviews. Changes in the anticipated operating strategies and annual output were constructed and estimated from a site visit to a WT operating in a high wind regime, and computerized statistical analysis of wind speed data from Mt. Washington.

In approaching user institutional issues three ownership options for wind turbines were examined: 1) the Navy, 2) the Utility; 3) a third party. The institutional factors are shown to have implications when measuring the economic value of a wind turbine project to each prespective user. Data were sought by which a simple model of economic performance could be created and applied to each user in order to demonstrate the economically preferred option. The analysis focused on issues related to how each owner would recover the capital cost of a wind turbine installation through electric purchase savings, fuel savings, or sale of wind generated electricity. In this connection the issue of wheeling of wind generated power from the mountains to the shipyard was examined to establish the feasibility of wheeling, and the cost.

In developing data for the analysis, the relevant federal and state laws pertaining to electric utility regulation, including the setting of rates for purchase by utilities of power from small producer facilities interconnected with the grid, and wheeling were examined. Then the proceedings of hearings by the New Hampshire Public Utilities Commission (PUC) on the setting of rates for the utility purchase of electrically generated by small producers were studied. Finally, personal interviews were conducted with representatives of the PUC, New Hampshire utilities, the New England Power Pool, and the New Hampshire Energy Office in order to confirm an understanding of how the law and organizational policies encourage or inhibit the development of alternative electrical energy resources such as wind.

3.0 WIND RESOURCE ASSESSMENT

3.1 Region of Interest

A prime objective of this section of the report is an assessment of the wind energy resource in the Mount Washington area of New Hampshire. Because Mount Washington and much of the land area in the immediate vicinity is within the White Mountain National Forest (WMNF), there are various levels of restriction on its use as a site for wind turbine generators (WT's). Chapter 5 outlines the various classifications of land area and summarizes the degrees of restriction. In summary, it is institutionally cumbersome to plan the installation of WT's within the WMNF. Therefore, the study, in addition to looking at the wind resource near Mt. Washington, broadened its geographic scope to go beyond the boundaries of the WMNF, seeking good wind sites in accessible state parks and private land.

Also because the wind resource is generally felt to be better in the more mountainous regions of the state, and because of the limited time frame of the study, the primary region of interest of this project has been in the central and northern regions where mountains predominate. A very few mountainous regions outside this area have, however, been examined.

The maps in Appendix A show the primary region of interest to be bounded, on the east by the Maine state line; on the north by an east-west line in the vicinity of Colebrook, N.H.; on the south by a line slightly north of Concord, N.H.; and on the west by a line at approximately the same longitude as the western boundary of the WMNF.

The Presidential range dominates the central region of the WMNF near Mount Washington. To the north of Mt. Washington lies first the Pliny and Pilot Ranges (within a northern segment of the WMNF) followed by a system of mountains centered roughly on Dixville Peak. The Mahoosuc Range lies east of the Pilots and represents prominent mountains of interest outside the WNMF, yet near Mt. Washington. South and primarily to the west of the WMNF, extending down past Lake Winnipesaukee to Concord, there are several private or state-owned lands that are potential sites for future installations of small clusters of wind turbine generators.

3.2 Approach to Wind Resource Assessment

The purpose of this section is to outline the approach that was followed in assessing the wind resource at potential WT sites in N.H. The wind resource assessment and prospecting techniques used in this survey are described along with the extent to which they represent the state-of-the-art in wind prospecting, a relatively new field.

Wind prospecting has been described by many researchers including Putnam (1948), Golding (1952) and Baker and Wade (1979). In each of these discussions the first step used in prospecting has been a preliminary evaluation of existing data. Each of these discussions has, however, pointed out that there are limitations

to the use of existing wind data particularly in complex terrain. Several studies have identified the Mt. Washington area as having good wind power potential (see Reed, 1974; Lockheed, 1976; Elliott, 1977). But in each of these assessments estimates were based primarily on limited upper air data and wind data collected at the Mt. Washington Observatory. Because many of the ptoential N.H. sites for WT's are remote from Mt. Washington and other stations with existing data, it was necessary to carry out a limited wind prospecting program to identify and assess specific sites.

Several authors have suggested that a first step in wind prospecting in data-sparse areas would be to identify topographic features such as gaps, saddlebacks, ridges perpendicular to the prevailing winds and well exposed peaks which are all known to be areas of accelerated wind flow (see Savino, 1974; Hewson et al., 1978; Frost, 1978, and Baker and Wade, 1979). This approach was followed in this study. In addition, interviews with local residents and knowledgeable observers were carried out in an effort to identify candidate sites. This approach has precedent in that public surveys have been noted by Renné and Elliott (1978) as a useful method of identifying areas of promising wind power potential. Baker and Wade (1979) point out that public contract can speed the survey process by providing valuable information on accessibility, land area availability of prospective sites and facilitate later arrangements for installation of equipment to measure wind.

An aerial survey of potential sites in a light aircraft was carried out. This approach is used to identify the presence of wind-deformed vegetation and examine potential site accessibility, terrain roughness, and site extent. Techniques for using various levels remote sensing in wind surveys have been described by Rosenfeld and Maule (1979).

Putnam (1948) was the first to use trees as an indicator of wind power in his survey of the winds in the Green Mountains of Vermont and the White Mountains of New Hampshire. Since then a number of studies have used trees in local wind surveys (see Lawrence, 1939; Sekiguti, 1951; and Yoshino, 1973). A Department of Energy funded study has quantified the relationship between the degree of wind deformation and the mean annual wind speed (see Hewson et al., 1979, and Wade and Hewson, 1979). The results of this study indicate that trees can be used as a quick, inexpensive and easy-to-use estimator of mean annual wind speed and these estimates, although subject to some uncertainty (about ± 20%), can be used to rank sites in terms of wind power potential. Wade and Hewson (1979) have also discussed other uses of trees in wind climate surveys, including their use as indicators of prevailing wind direction, and as an ecological indicator of severe wind and ice damage.

Since the rotors of wind turbines may extend to great heights above the ground (the blade tip for the Boeing MOD-2, 2500 kW machine will extend to 350 feet above the ground) and in this layer there is considerable vertical variation in wind speed, it is important in evaluating a potential site to be able to identify how much vertical shear might be expected under prevailing wind flow regime. Knowing shear permits not only a better estimate of the average wind speed over the rotor disc, but also an estimate of the degree of cyclic bending loads which may be sustained by blades of horizontal axis wind turbines (HAWT) with each

rotation. The simple form of the equation generally used to describe shear flow over a surface is given by equation (3-1). In this

$$V_2 = V_1 \left(\frac{z_2}{z_1}\right)^{\alpha} \qquad (3\text{-}1)$$

equation V_1 and V_2 are velocities at heights z_1 and z_2 respectively. The exponent α is the parameter which describes the shear profile. The NASA Lewis Research Center has developed a more precise (yet slightly more complex) shear law which will not be described here (D. Spera, NASA Conference on Wind, April 1979).

The use of the wind shear power law representation shown in equation (3-1) has been used by investigators for many years. According to Frenkiel (1961), locations with a power law exponent of less than 0.1 are ideal for operation of large wind turbines. This study obtained an average value of approximately 0.11 on many New Hampshire peaks.

One device which has been used to evaluate vertical wind shear is the Tethered Aerodynamically Lifting Anemometer or TALA-Kite. This kite has been suggested as a wind prospecting tool by Baker and Wade (1979), Baker et al., (1979), and Shieh and Frost (1979). The kite provides an inexpensive, easy to use, portable anemometry system for evaluating the effect of local topographic and roughness features on the vertical structure of the wind. A measure of the turbulent nature of the wind at a specific site can be rapidly obtained from the ratio of the scatter of instantaneously measured wind speeds and the mean wind speed.

Short term wind surveys have been found to be a useful tool for comparing prospective sites. These wind measurements should also be compared to the nearest location where wind data is recorded on a continuous basis so that inferences can be made on the relative strength of the wind (see Baker and Wade, 1979).

The above techniques, which provide a varied, reliable, and inexpensive approach to locating good wind power sites, were very appropriate to the study reported herein because of the short time frame.

3.3 Mt. Washington Observatory Data Analysis

In order to obtain a benchmark of data at a reliable New Hampshire mountain meteorological station, a study was conducted with five years of data from the Mount Washington Observatory station on the summit. These data are evaluated even though it is recognized elsewhere in this report (Sections 4 and 5) that severe icing, land restrictions, and high winds limit the use of WT's on Mount Washington. Toward this end, two parallel efforts were undertaken to collect all relevant climatological information relating to Mt. Washington. The first effort involved a literature search for previous work done on evaluating Mt. Washington climatological data. This effort was made in order to minimize redundancy. The second

task involved the collection and appraisal of the meteorological data emanating from the Mt. Washington Observatory. A limited amount of these data were analyzed in detail and related to operating parameters of specific WT's (see Chapter 4).

3.3.1 Mean Characteristics on Mount Washington Summit

The Mount Washington Observatory is located on the summit of Mount Washington in Gorham, New Hampshire. At 1918 meters (6288 feet), the summit is the highest point in the northeastern United States. The first regular meteorological observations started in 1870, while the present observatory dates from 1932.

Weather on the summit is reputed to be among the most severe ever recorded. Over the 39-year interval 1935-1974, the measured mean annual precipitation at the Observatory is 206 cm (80.95 inches), while the mean annual snowfall is 595 cm (234.4 inches). For at least 300 days of the year the summit is shrouded by clouds at least part of the day. The highest temperature ever recorded is 22°C (72.2 °F); the lowest is -44°C (-47°F). The highest wind velocity ever recorded, 103 m/s (231 mph) was recorded at the Mt. Washington summit on April 12, 1934. Average figures published by the National Weather Service are given in Table 3.1 (Mount Washington Observatory, 1979).

3.3.2 Applicability of Mount Washington Observatory Data

The meteorological data measured at the Mount Washington Observatory are available in the following two forms from the National Climatic Center (NCC), in Ashville, N.C.:

- Surface Weather Observation
- Local Climatological Data (LCD)

The Surface Weather Observation (WB Form B-16) is a log of hourly average wind speed and direction for 24 hours as well as the daily peak gust and direction. From this raw data, NCC produces monthly summaries, known as Local Climatological Data (LCD). LCD's contain both daily average wind speeds for any given month plus the average wind speed for the month. A review of two wind data summaries (Changery, 1975, and Changery et al, 1977) indicated that there was no additional wind data available for the observatory. Accordingly, both the daily Surface Weather Observations and the monthly LCD summaries for the ten-year period 1969-1978 were acquired and analyzed. These data were reviewed for completeness and continuity of record. This effort yielded a list of 5 years during which wind speed and direction were recorded every hour for 24 hours a day. A 5-year period is generally considered the length of time necessary to establish statistically significant trends in meteorological phenomenon. To validate this point, the curves of Figure 3-1 were produced. This figure indicates the variation in monthly average wind

TABLE 3–1
NORMALS, MEANS AND EXTREMES AT MOUNT WASHINGTON

(Annual figures based on 1941–1970 records, published by the U.S. Weather Bureau – Local Climatological Data).

Temperature:	
Normal Monthly Average	-3°C (26.9°F)
Record Highest (Aug. 1975)	22°C (72.2°F)
Record Lowest (Jan. 1934)	-43.9°C (-47.0°F)
Precipitation:	
Normal Yearly Total	1.93 m (76.17")
Maximum in 24 hours (Feb. 1970)	26.4 cm (10.38")
Snow, Sleet:	
Mean Total	5.95 m (234.4")
Maximum Monthly (Feb. 1969)	4.39 m (172.8")
Maximum in 24 hours (Feb. 1969)	1.25cm (49.3")
Wind:	
Mean Hourly Speed	15.7 m/s (35.2 mph) W
Peak Gust (April 1934)	103.3 m/s (231.0 mph) SE
Mean Number of Days –	
Clear	51
Partly Cloudy	73
Cloudy	241
Heavy Fog	310

Table excerpted from Mount Washington Observatory, 1979

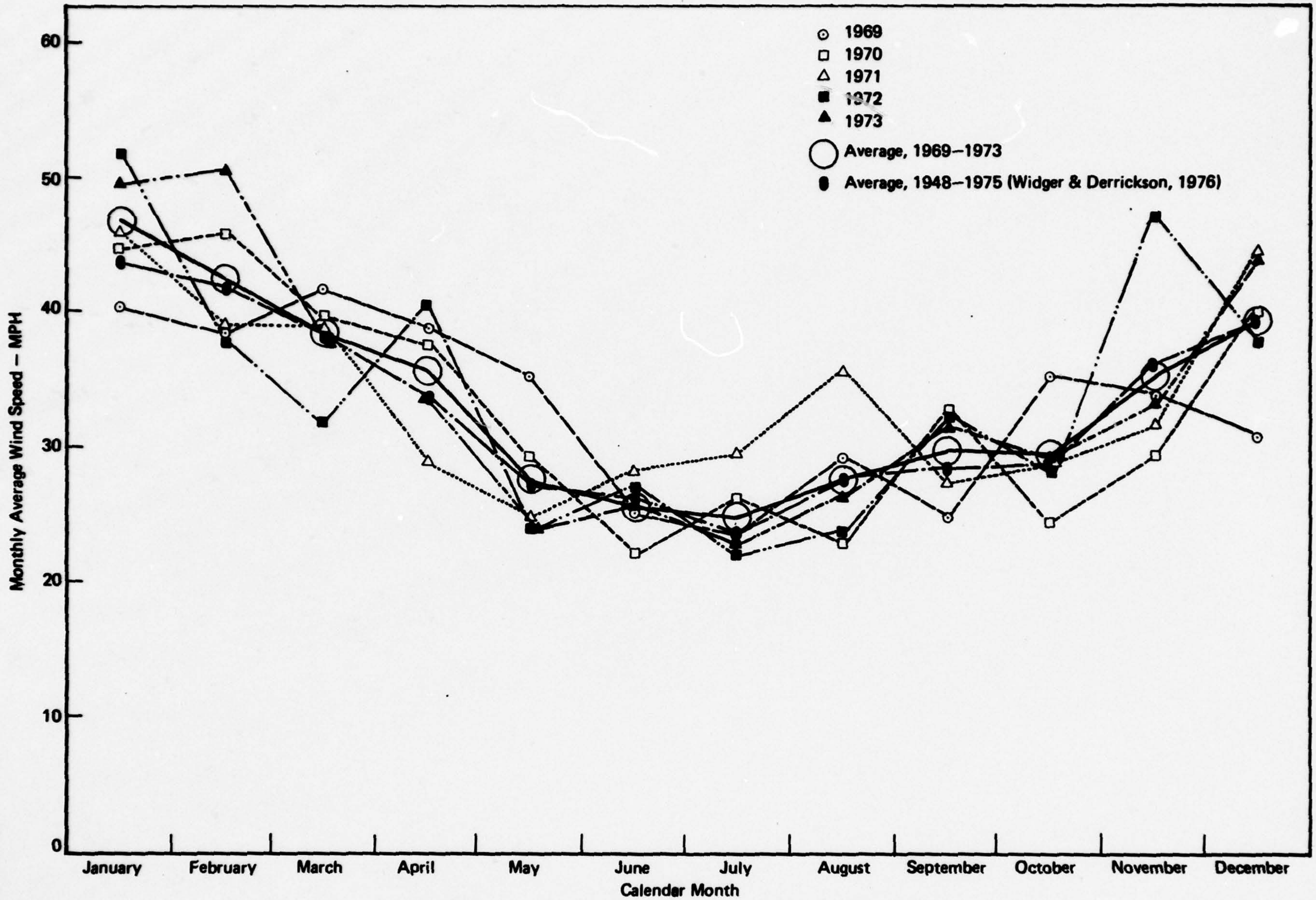


FIGURE 3–1 VARIATION IN MONTHLY AVERAGE WIND SPEED MOUNT WASHINGTON

speed for the five years 1969 through 1973. The year-to-year variation in monthly average wind speed is smoothed by plotting the average of monthly wind speeds for the same 5-year period. As can be seen, this 5-year average curve compares very favorably with the 28-year average (1948-1975) reported by Widger and Derrickson (1976). From this analysis, it can be concluded that the five-year data base is representative of long term trends.

3.3.3 Analysis of Wind Data

The instantaneous wind power per unit area (P/A) is proportional to the density of the air (ρ), and the cube of the instantaneous wind speed (V) as follows:

$$P/A = 1/2\ \rho V^3 \qquad (3\text{-}2)$$

where A is the swept area of the wind turbine blades. Because of the strong dependence of available wind power on wind speed, it is extremely important to find acceptable sites with the highest average wind speed. In order to obtain long term estimates of average wind power, short term wind speed measurements should be cubed and then these cubic values averaged over the period of interest. Most meteorological records, however, only report long term average wind speeds values. Therefore, in order to reduce errors and computation time, it is customary to introduce a proportionality constant K_b when attempting to calculate available power based on average wind speeds (Justus, et al, 1976) as follows:

$$K_b = \frac{\langle V^3 \rangle}{\bar{V}^3} = \frac{1}{T}\int_0^T V_i^3\, dt \Big/ \frac{1}{T}\int_0^T \bar{V}^3\, dt \qquad (3\text{-}3)$$

where V_i are short term averages and $\bar{V}$ represents longer term (e.g., weekly, monthly) average wind speeds. In order to calculate K_b, it is necessary to have estimates of wind speeds over shorter intervals (e.g., 1-hour averages V_i) and then compute a monthly value for K_b. This monthly value can then be assumed to be constant for the same month in other years at the same site. K_b was calculated for each month based on 1976 hourly average wind speeds. The results are shown in Figure 3-2 and Table 3-2. In order to assess the sensitivity of the calculation of K_b to data from different years, data from 1969 were similarly analyzed. The results are given in Figure 3-2 and Table 3-3. Equation 3-2 can be rewritten for cases where only long term wind speed averages (daily, monthly, etc.) are available.

$$P/_A = 1/2\ \rho\ K_b\ \bar{V}^3 \qquad (3\text{-}4)$$

Specific site wind characteristics are customarily represented by means of a wind speed frequency distribution. The distribution identifies

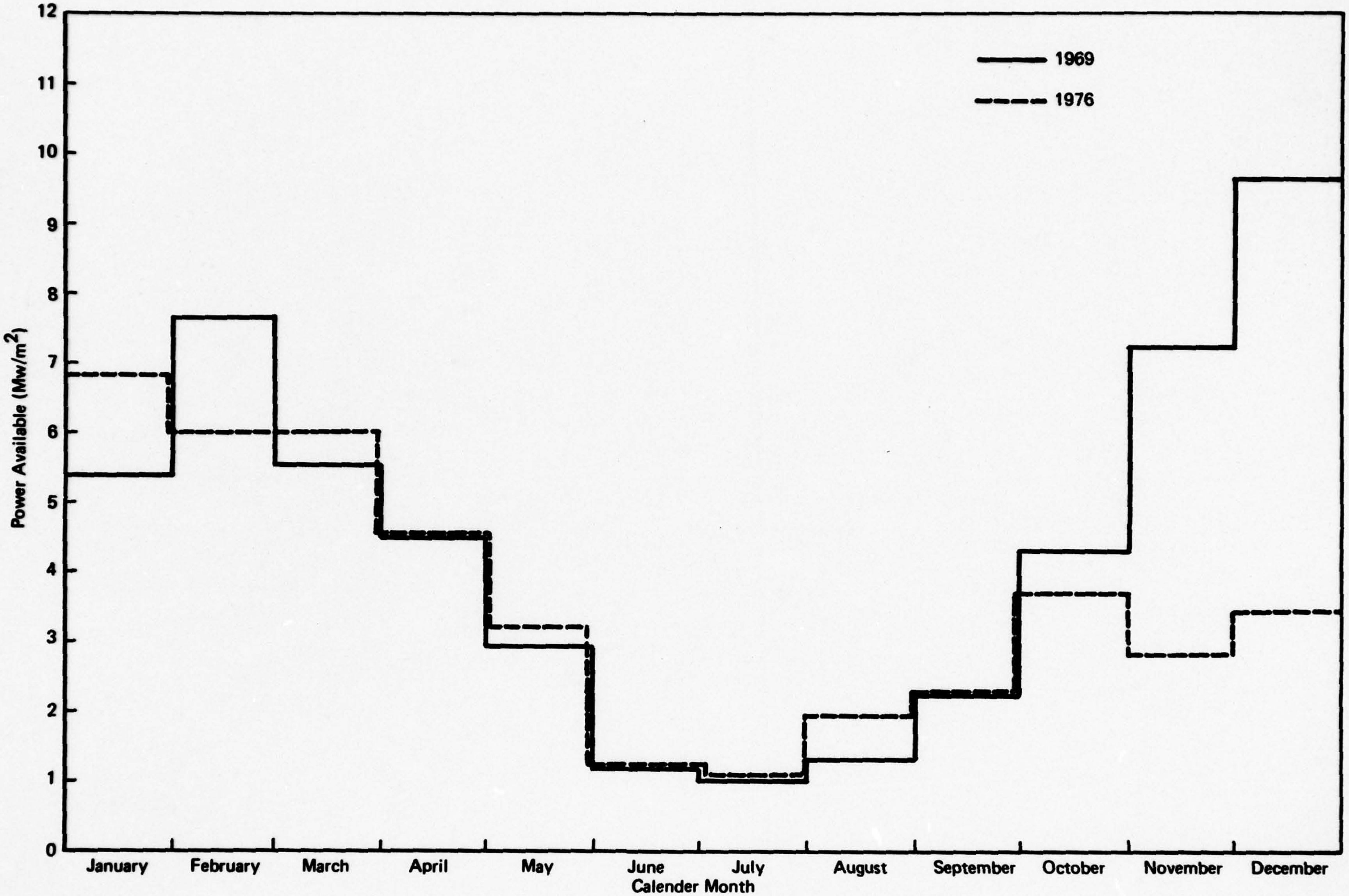


FIGURE 3–2 MONTHLY AVAILABLE WIND POWER MOUNT WASHINGTON

TABLE 3–2
WIND ASSESSMENT
MOUNT WASHINGTON
YEAR: 1976

Month	$K_b = \frac{\langle V^3 \rangle}{\bar{V}^3}$	Weibull Parameter		Power Available (w/m^2)
		K	C	
January	1.59	2.48	20.89	5362
February	1.41	2.95	24.30	7626
March	1.48	2.65	21.58	5509
April	1.66	2.33	19.65	4497
May	1.94	1.96	16.23	2911
June	1.71	2.32	12.63	1172
July	2.17	1.79	11.10	1022
August	2.11	1.85	12.09	1281
September	1.82	2.08	15.29	2224
October	2.06	1.83	18.00	4458
November	1.44	2.81	23.95	7183
December	1.58	2.45	25.51	9609

TABLE 3–3
WIND ASSESSMENT
MOUNT WASHINGTON
YEAR: 1969

Month	$K_b = \frac{\langle V^3 \rangle}{\bar{V}^3}$	Weibull Parameters		Power Available (w/m^2)
		K	C	
January	2.20	1.80	20.29	6851
February	2.23	1.70	19.22	5969
March	1.73	2.21	21.11	5976
April	1.67	2.23	19.61	4483
May	1.60	2.38	17.75	3143
June	1.67	2.31	12.84	1203
July	1.97	1.97	11.87	1121
August	1.77	2.16	14.77	1936
September	2.41	1.61	12.28	1585
October	1.81	2.09	17.89	3647
November	1.58	2.43	17.02	2794
December	2.48	1.58	15.30	3388

TABLE 3–4
ANNUAL POWER AVAILABLE
MOUNT WASHINGTON

Year	Annual Power Available w/m^2
1969	3450
1970	3150
1971	3450
1975	3450
1976	4325
5 Year Average	3565

a probability density function or the number of hours per year that the wind can be expected to blow at a given speed (Justus et al., 1976).

Putnam (1948) described this probability distribution curve as a Pearson Type 1 family of curves. Justus (1978) argues that from a practical standpoint, a two parameter Weibull distribution represents a good empirical fit for the wind speed frequency distribution data. The Weibull distribution for wind speed V can be expressed in terms of the probability density function P(V), the scale factor c, and the shape factor, k, as shown in equation (3-5). The Weibull distribution for Mt. Washington observatory data for each month during a representative year is given in Appendix B.

$$P\,(V) = (k/c)\ (V/c)^{k-1}\ \exp\ [-\ (\bar{V}/c)^{k}] \qquad (3\text{-}5)$$

If mean wind speed $\bar{V}$ and the Weibull parameters are known or estimated, several important wind distribution properties can be evaluated. Conversely, if time series measured data are available, such as for Mount Washington, it is possible to work backwards and determine the actual values of C and K that best characterize the actual data.

The available wind power as calculated from hourly data for the years 1969 and 1976, are plotted together in Figure 3-2. It is interesting to note the close agreement of monthly average power during the calmer summer months and the pronounced variation during the windier winter months. Neither feature would be obvious from studying the monthly variation in wind speed shown in Figure 3-1. The scatter in wind speeds for the five years displayed in the monthly averages in Figure 3-1 suggests corresponding inter-annual variability in available wind power. To determine the inter-annual variability of the available wind power, the years 1969 through 1971, 1975 and 1976 were analyzed and compared. The monthly proportionality constants, K_b shown in Table 3-2 were applied to monthly average wind speeds for the corresponding months of 1970, 1971, and 1975 while hourly average wind speed data were used for 1969 and 1976 in order to estimate the monthly average available wind power. The values for each month were then summed in order to obtain the annual average value. The results for the five good data years are listed in Table 3-4 and plotted in Figure 3-3. The most interesting feature of this analysis is the small year-to-year change in annual power availability. An overall average yearly power availability of approximately 3.5 MW/m^2 is indicated. Appendix B also contains a summary of the average diurnal variation of available wind power by season of the year.

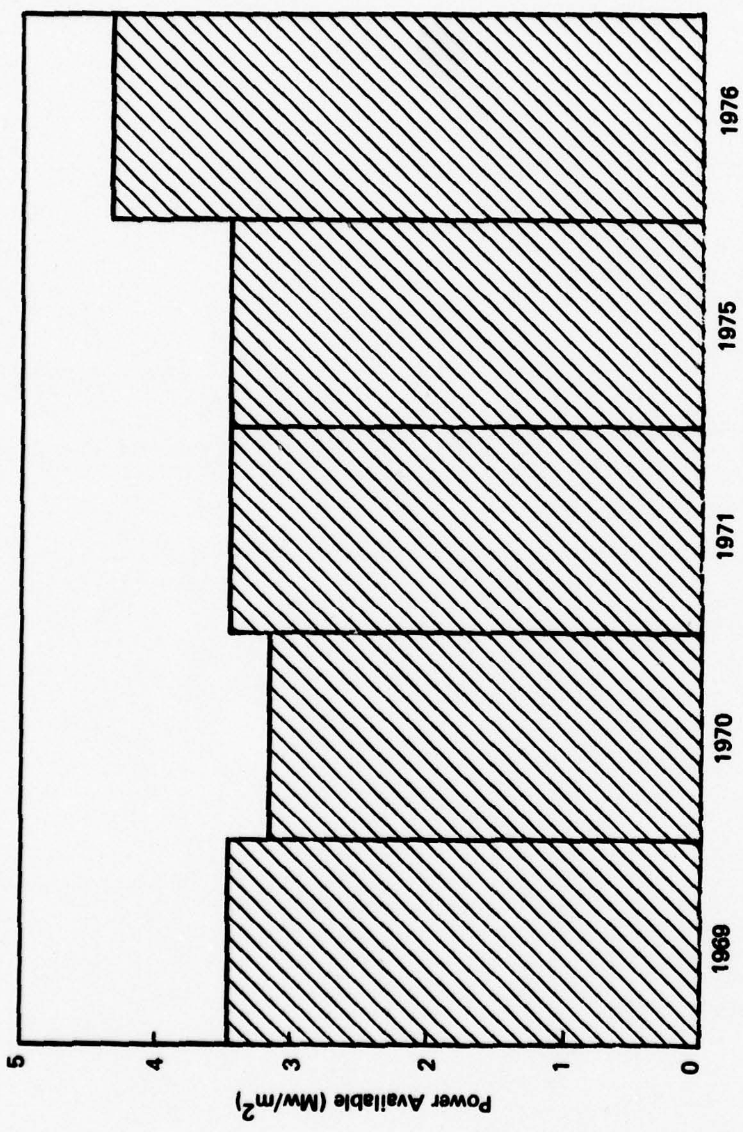


FIGURE 3–3 AVERAGE ANNUAL WIND POWER AVAILABLE
MOUNT WASHINGTON

3.4 Remote Sensor Data

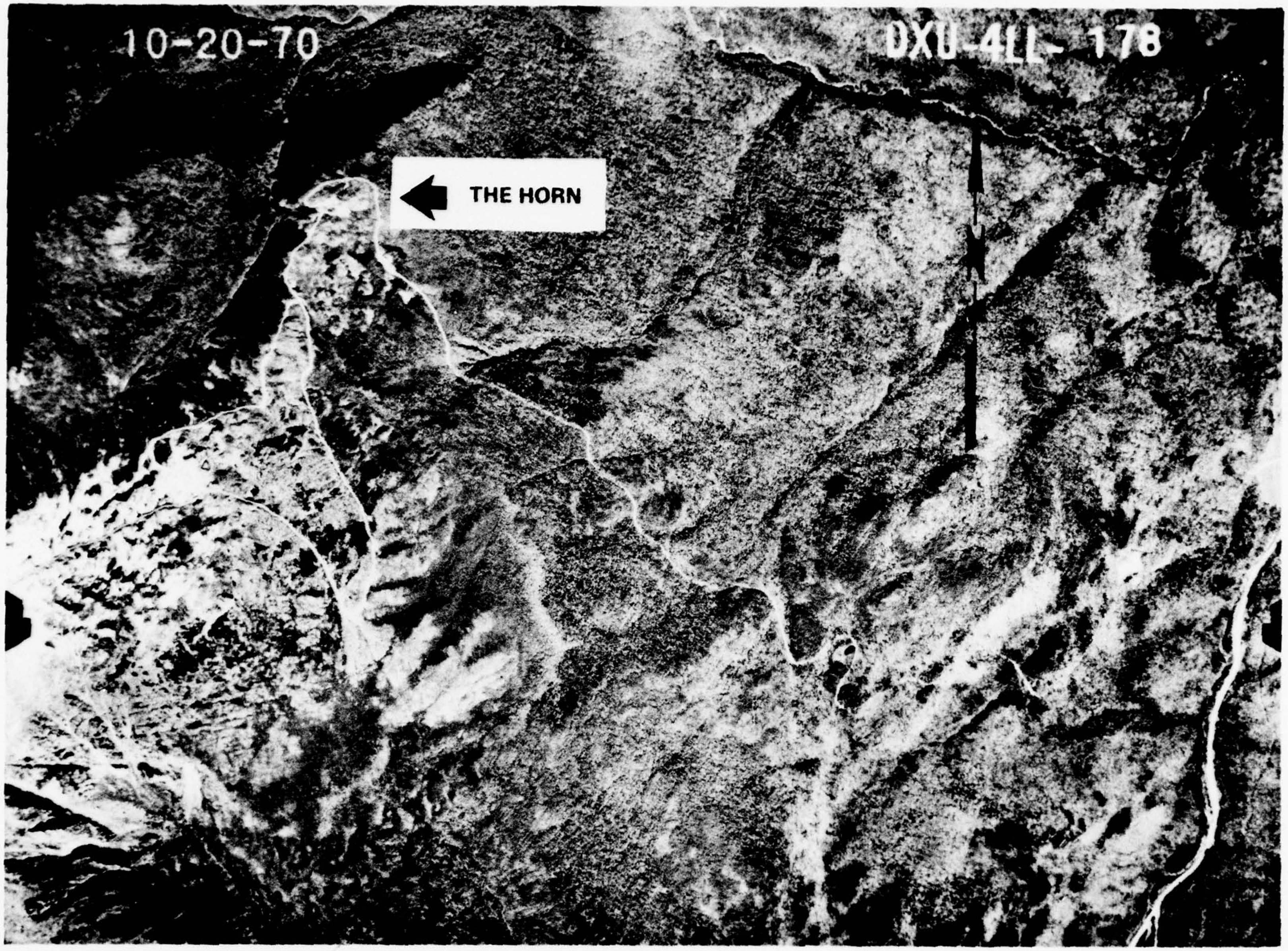
Early in the assessment program it was recognized that there were fundamental problems associated with analyzing the wind energy potential in terrain as complex as the White Mountains of New Hampshire. The two major problems are the large horizontal variation in wind speeds that can occur over distances of less than a mile and the lack of reliable mountain wind data. To overcome these barriers, attempts were made to make use of various aerial imagery data available from the EROS Data Center, Sioux Falls, South Dakota. It was hoped that photographic imagery would reveal areas of wind flagged vegetation or wind eroded eolian features.

3.4.1 Aerial/Satellite Photography

The Earth Resources Observation Systems (EROS) Program of the U.S. Department of the Interior was established in 1966 to apply remote-sensing techniques to the inventory, monitoring and management of natural resources. They provide access primarily to NASA's LANDSAT imagery, aerial photography acquired by the U.S. Department of the Interior, and the U.S. Department of Agriculture and photography and imagery acquired by NASA from research aircraft and from Skylab, Apollo, and Gemini spacecraft. A review of this resource information and an assessment of its usefulness to the program, led to the conclusion that aircraft aerial photographs would best meet our needs as they give better definition and resolution than any of the satellite photographs.

Therefore, stereoscopic pairs of photographs covering much of the study region were acquired and analyzed. The best imagery available was taken at an altitude of about 4,880 m (16,000 ft.) MSL. At this height, with Mount Washington (6288 MSL) 3,050 m (10,000 feet) below the camera, it was extremely difficult to spot vegetation and areas of the ground that have suffered from the long term effects of high and persistent winds. Even known areas having extreme wind flagged vegetation such as photograph of the horn on Mount Washington taken from 4880 m (16,000 feet) (see Fig. 3-4) were hard to discern as such. Summits that were seen to be devoid of vegetation required cross-checking with topographic maps in order to determine whether or not they were severely wind swept or merely above the timber line. In some instances, barren sites below the timberline turned out to be the result of forest fire activity.

A strong element of the approach to wind resource assessment in this study was, however, to use a light, fixed wing aircraft to enable the examination of potential sites, and any wind flagged vegetation. At each site a set of photographs were taken with a 35 mm camera using a 135 mm telephoto lens. The elevation of most pictures was approximately 150 meters (500 feet) above ground. The photographs were later studied, looking for detailed evidence of wind flagged vegetation. Although some of the potential wind turbine sites appearing on the final list were first identified from aerial examination and interpretation of aerial photographs, the technique proved to be less than ideal. The strongest reason for this is that in many cases the dense canopy cover of deciduous trees found in New Hampshire masks wind effects on the vegetation. It was necessary to look for a few trees that penetrated through the canopy and had evidence of flagging.



Source: USDA, Agricultural Stabilization and Conservation Service.

FIGURE 3–4 AERIAL PHOTOGRAPH OF THE HORN OF MOUNT WASHINGTON

3.5 Smith-Putnam and Other Data

3.5.1 Smith-Putnam Project

Much of the modern day WT technology and experience with resource assessment dates from the Smith-Putnam project of the 1940's (Putnam, 1948). The experimental wind turbine generator of 1250 kW capacity was erected on Grandpa's Knob, a mountain with an elevation of 2000 ft., near Rutland, Vermont. With little hard data to guide them, these engineers made many simplifying assumptions and estimates. In general, they believed that good wind turbine sites would be found on well exposed ridges perpendicular to the prevailing winds (westerly in New England). They knew that wind velocity generally increases with the height above the ground. In an effort to model the effect of mountain geometry on the speed-up or retardation of wind passing over the mountains, they assumed that well defined ridges acted as air-foils and introduced the concept of speed-up factors. With these assumptions and some meteorological data they concluded that the mean wind speed at Grandpa's Knob would be about 11 m/s (24 mph). Wartime emergencies forced the project forward before this estimate could be confirmed with anemometer measurements. It was not until the wind turbine generator had been erected that they learned that the average wind speed at the site was only about 7.6 m/s (17 mph). Owing to the fact that power is proportional to the cube of the wind speed, the 3 m/s (7 mph) difference between estimated and actual wind speeds resulted in 30% less power generation than anticipated. Although not a complete success economically, the project indicated the practical possibility of employing large machines to generate power from the wind.

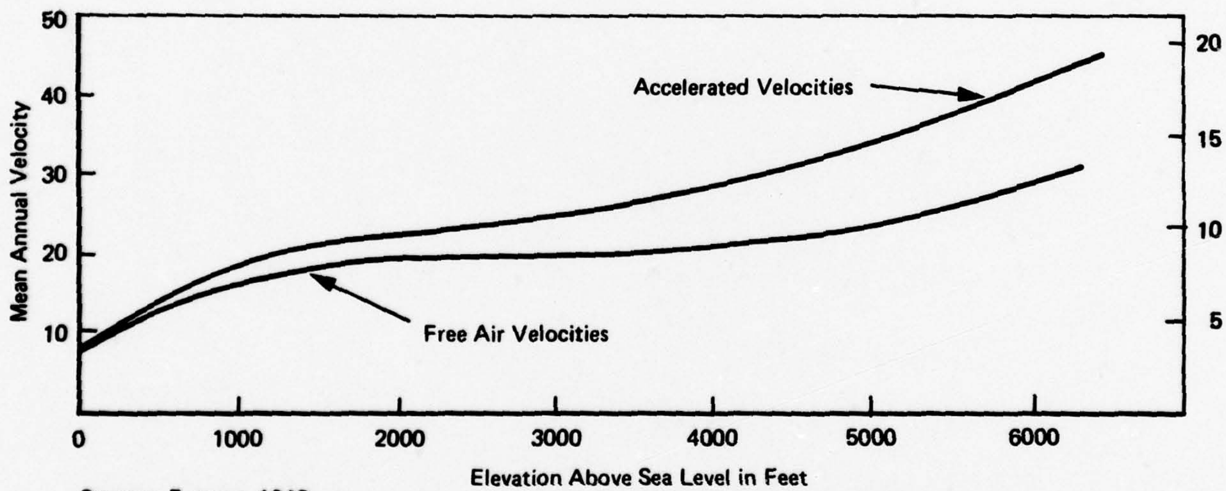
As the Smith-Putnam project matured, between 1940 and 1945 a wind survey was undertaken in the Green Mountains of Vermont and in other locations, principally Mount Washington, New Hampshire. Twenty sites were selected with altitudes varying between 610 and 1220 m (2000-4000 feet). Anemometers were erected in groups of three or four, at different heights from 12 to 56 m (40-185 feet) above ground. The intent was to develop a data base from which they could estimate long term wind flow patterns in northern New England.

These anemometers were monitored for fairly short periods, often less than 6 months (a few weeks in some cases). This is unfortunate since it is generally recognized that a recording period of at least one year is needed (and 5 years is better still) to include all climate conditions likely to be experienced. Nevertheless, this work with its admitted shortcoming stands as the best information completed to date on winds in northern New England.

The lower curve of Figure 3-5, which is extracted from Power From The Wind (1948), indicates mean annual wind speed (free stream) as a function of elevation above sea level. The left portion of the curve is based on long term data from Blue Hills Observatory in Milton, Massachusetts. The right side of the plot results from the Smith-Putnam project's estimate of the free stream wind speed at the altitude of Mount Washington; estimated at 13.4 m/s (30 mph). The flat middle portion of the curve suggests a more or less constant wind speed of about 7.6 m/s (17 mph) could be achieved on any well exposed site between the altitudes of 610-1220 m (2000-4000 feet). It is in this altitude range that most of the data were actually recorded that allowed the curve to be plotted.

TABLE 3–5
SPEED-UP FACTORS AT VARIOUS SITES ON MOUNTAIN RIDGES IN NEW ENGLAND (AFTER PUTNAM, 1948)

Station	Height above sea level m(ft)		Speed-up factor	
			Observed	Wind-tunnel
Pond	458	(1500)	0.84	1.29
Biddie I	631	(2070)	0.90	
Grandpa's	650	(2130)	0.88	
Biddie Proper	656	(2150)	0.84	
Seward	677	(2220)	0.94	
Chittenden	760	(2490)	0.89	
Herrick	824	(2700)	0.92	
Glastenbury	1189	(3900)	1.04	1.44
Pico Peak	1253	(4110)	1.10	
Mt. Washington	1961	(6430)	1.47	1.30



Source: Putnam, 1948

FIGURE 3–5 VELOCITY VS ELEVATION NORTHERN NEW ENGLAND

The long term average wind speed on the summit of Mount Washington is approximately 15.6 m/s (35 mph) at an anemometer height which has varied between 9.5 and 12.0 meters (31-40-feet) (Changery, 1978). The Smith-Putnam engineers scaled this up to their hub height 42.7 m (140 feet) and got an estimated 19.7 ± 1 (44 ± 3 mph) wind speed. It is this point that sets the right hand end of the upper curve in Figure 3-5. The vertical distance between the two curves represents their estimate of the speed-up effect achieved by the air-foil shape of mountains. They also suspected that this speed-up factor increased with altitude. A summary of these estimates of speed-up factor is presented in Table 3-5. It is this over-emphasis on the acceleration of wind over mountain tops that led them to the previously mentioned 3.9 m/s (7 mph) error in average wind speed estimates at Grandpa's Knob.

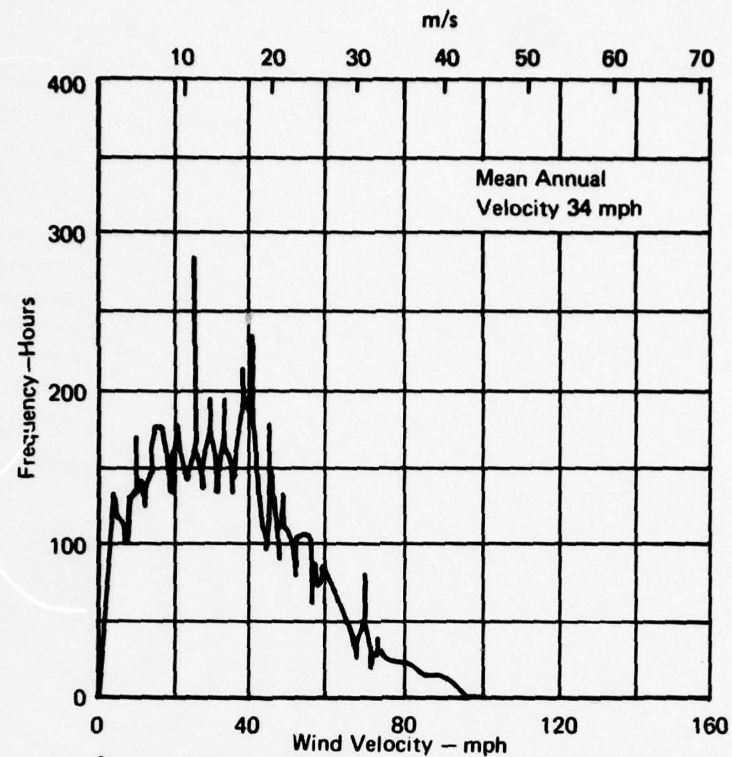
Years later, one of the contributors to the Smith-Putnam project, Dr. Sverre Petterssen, re-evaluated the concept of speed-up factor. He concluded that the speed-up factors reported in the Smith-Putnam work (Table 3-5) were much in doubt; the uncertainties being due to difficulties in determining the undisturbed wind at the level concerned. The apparent increase in the speed-up factor with elevation above 915 m (3000 feet) should be accepted with great skepticism, because when those estimates and measurements were made, their knowledge of the normal increase with height of the free-air stream was inadequate. It was his opinion that there were really no firm observations to show that speed-up factors in excess of unity are obtainable over large mountain ridges (Petterssen, 1961).

Putnams' work (1948) deals primarily with the 1250 kW wind turbine which was erected on Grandpa's Knob. However, in the process of analyzing the synoptic weather patterns in New England, much use was made of Mount Washington Observatory data. The frequency distribution curve of Figure 3-6 (compare also with Figure 4-9) is based on 60 months of anemometry data from Mount Washington and was reported in an earlier work by some of the contributors to the Smith-Putnam project (Wilcox & Dornbirer, 1945). Putnam published a smoothed version of this curve which is shown in Figure 3-7. Each curve gives the number of hours annually that the wind is blowing in each speed range. This type of wind speed data from the Mount Washington Observatory was used in conjunction with the power characteristics of specific machines was enabled our appraisal of the annual WT energy production for winds between wind turbine generator cut-in and cut-out velocity (see Section 4).

The wind rose data of Figure 3-8 is based on the same 60 months of observatory data. It shows that the dominant wind direction at the summit is from the west. This would suggest that for many of the high peaks of New Hampshire the prevailing flow is from the west and northwest, the direction of the main circulation of the winds aloft. This estimate was borne out by an examination of the prevailing direction of flagging on many trees observed at lower elevations than Mount Washington and other New Hampshire peaks.

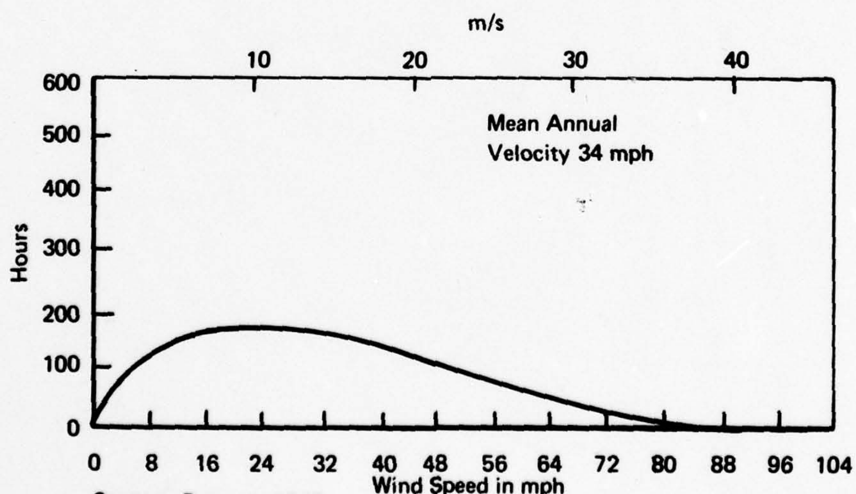
3.5.2 Other Data

Initially, a great deal of effort was put into obtaining and evaluating existing climatological data in order to develop an overall assessment of the wind energy potential in New Hampshire. However, existing data is either very scarce, or of questionable value.



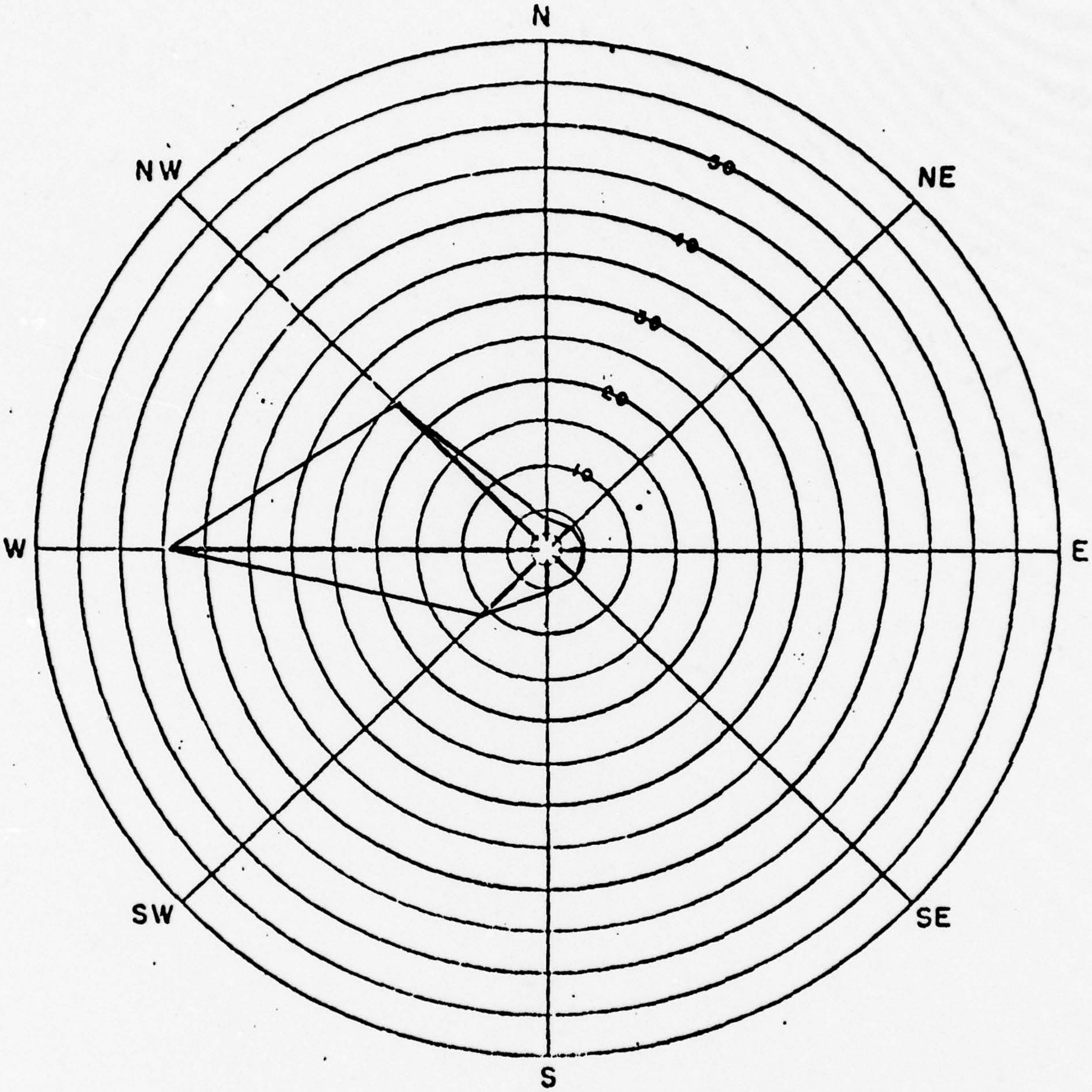
Source: Putnam, 1948.

FIGURE 3–6 WIND VELOCITY FREQUENCY DISTRIBUTION MOUNT WASHINGTON



Source: Putnam, 1948.

FIGURE 3–7 WIND VELOCITY FREQUENCY DISTRIBUTION MOUNT WASHINGTON



Source: Putnam, 1948.

FIGURE 3–8 WIND ROSE, MOUNT WASHINGTON (DATA IN PERCENT)
Elevation: 1920 m (6300 ft)

Ski Lift Data

Some ski areas such as Cannon and Wildcat Mountains have anemometers, but data from these sources are thoroughly unreliable because of the limited exposure of the anemometer, the frequent sensor failures, and the fact that the anemometers are largely uncalibrated.

Airport Data

Data from all significant airports in New Hampshire and adjacent Maine and Vermont, were obtained and studied. Virtually all such locations are in sheltered valleys, with average annual wind speeds never greater than 4.5 m/s (10 mph) and very often less than 3 m/s (7 mph).

Forest Fire Towers

The United States Forest Service Fire lookouts often collect wind data during the forest fire season. Although these locations are generally on well exposed hills or mountain tops, the data are usually only reported once per day (generally at 1400 hours). Mean annual wind speed can only be inferred since these installation do not operate during the winter (the windiest season). The data which is available was acquired and studied. It was found that the sites surrounding the WMNF, such as Twin Mountains, Gorham and Rumney, New Hampshire, routinely report wind speeds less than 4.5 m/s (10 mph). The data available cover only a two-year period; not a statistically significant length of time.

Although there are numerous summarized data sets available for various locations in New Hampshire, they seem to be of questionable value from the standpoint of instrument exposure, record length, observation practices, etc. The conclusion is that existing data are quite meager and that the locations where data are available are generally poor wind power sites.

Miscellaneous Wind Data Sources

Two other sources of weather data became available to the general public during the course of this program. One site is the 10-meter (33 feet) high meteorological tower at the Brown Paper Co. in Berlin, New Hampshire. This tower is instrumented with wind speed and direction indicators to monitor smoke stack emissions for compliance with Environmental Protection Agency (EPA) regulations. Data from this installation will be made available through the office of the New Hampshire State Climatologist. A well exposed 100-meter high tower with anemometers at three elevations is planned for the near future (mid-1980) at the Brown Paper Co. The data from this group of sensors should provide an excellent opportunity to study vertical wind speed distributions in a valley environment.

The other new location is the National Weather Service (NWS) station in Franconia, New Hampshire. This is a valley station located near the base of Cannon Mountain. The station became operational late in August, much too late to be of use during this study program. Future studies may, however, find it useful to couple data from this source with a program of anemometry at the summit of Cannon Mountain in order to map vertical profiles of wind speed in the Franconia Notch Area and study their relationship to anemometry records from the summit of Mount Washington.

3.6 Analytical and Physical Modeling Techniques

Early in the program various modeling techniques were evaluated as possible prospecting tools.

Meroney (1979) has described application of physical modeling in a wind tunnel to wind prospecting. Physical models of terrain are placed in a wind tunnel and under certain conditions the flow aroung the model should simulate the winds flowing around the actual terrain feature. Koch and Pickering (1978) have described statistical modeling techniques for interpolating or extrapolating from a point where winds are measured to other points where no data are available.

Sherman (1979) and Traci (1979) have described numerical modeling approaches in which numerical solutions to the governing equations of the atmosphere can be obtained using high speed computers. Despite the simplifying assumptions which must be made, these solutions can often simulate real winds over complex terrain.

In analytical modeling the equations governing atmospheric motion are set up more rigorously so that more meaningful solutions and greater understanding of wind flow can be achieved. However, in complex terrain the variable atmospheric boundary conditions, frictional effects and other factors have resulted in very little progress in this area of modeling.

Current techniques allow accurate analytical estimates of wind flow over simple shapes (cylinders, cubes, etc.) with reasonable fidelity. However, the ability of models to predict flows over complex mountain or hilly terrain is largely unverified at this time. Investigators have experienced difficulty in validating these models in real situations owing to the lack of appropriate historical meteorological data. The findings of this study are that at this time, analytical and numerical modeling techniques are inappropriate and unverified in the type of complex terrain of interest.

3.7 Previous Study Results

3.7.1 Cannon Mountain

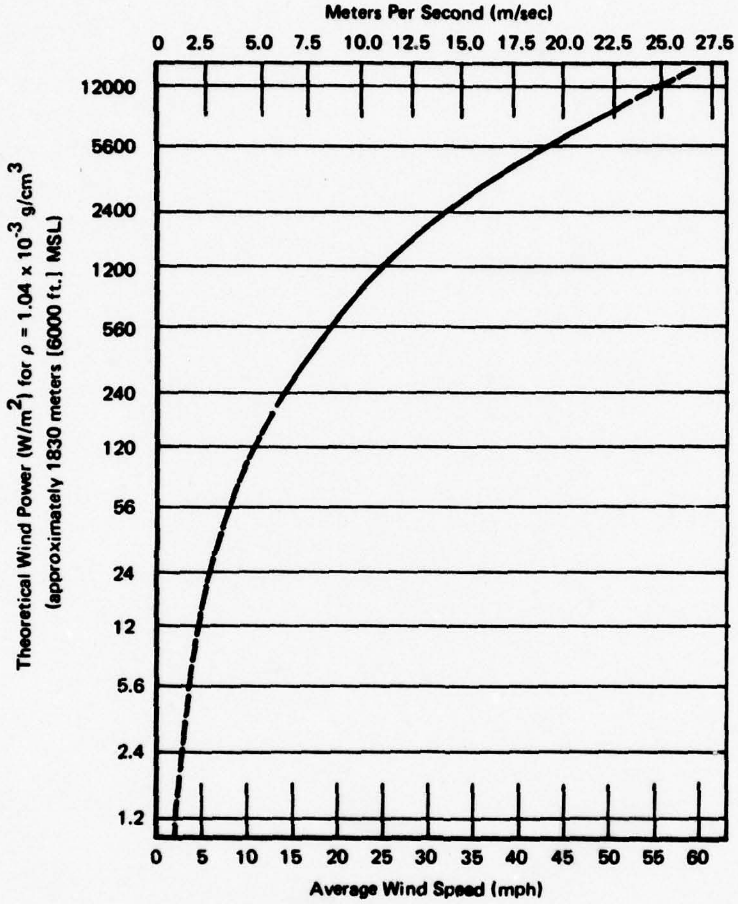
During the fall and winter of 1972-1973, the University of Massachusetts (UM), supported by Mount Holyoke College and the U.S. Forest Service, conducted a climatological research project at numerous locations in the WMNF. The object of the program was to evaluate extreme winds in varying terrain conditions (Glidden, 1979). Thirty monitoring stations were reporting data during this period but special problems with icing made it difficult to keep them all operational.

One portion of the UM program has been reported by the principal investigator, D.E. Glidden (Glidden, 1974). It concerns an episode of severe winds recorded on Cannon Mountain. On April 2, 1973 gust maxima exceeding 89.4 m/s (199.5 mph) were recorded several times on the summit of Cannon Mountain. Gusts in excess of 44.7 m/s (100 mph) on Cannon Mountain are not unusual phenomena, and are believed to be related to severe down-slope components of the gradient wind induced by Franconia Notch.

3.7.2 Mount Washington

A study was undertaken by Widger (1976) to develop a method for estimating annual wind power for a site area based only on average wind speed data. The shortcut method attempts to avoid extensive data processing but acknowledges that the results should be supported by more detailed analyses before an investment is made in major power generating equipment. Long term data from Mount Washington Observatory was used to validate the technique. A long term annual average wind speed of 14.8 m/s (33.1 mph) is reported with a range of monthly average wind speeds of 11-19.6 m/s (24.7 mph to 43.8 mph). These numbers are in excellent agreement with findings of this report, Putnam (1948) and others. The result of Widger's work is portrayed by the curve of Figure 3-9. This curve establishes the relationship between average annual wind speed and theoretical wind power. A wind speed of 15.6 m/s (35 mph) yields an annual theoretical wind power of 3300 W/m^2 at an elevation corresponding to Mount Washington. This value is within 6% of the 3500 W/m^2 discussed in Section 3.2.2.

Widger (1976) also developed a simplified procedure for obtaining wind speed frequency distribution based on only average and fastest mile speeds. This approximate method is adequate for rough determinations of average wind power but as pointed out by Baker and Hennessey (1977) this approach can underestimate the available wind power by up to 60%.



Source: Widger and Derrickson, 1976.

FIGURE 3–9 NOMINAL THEORETICAL WIND POWER (W/m^2) AS A FUNCTION OF AVERAGE WIND SPEED

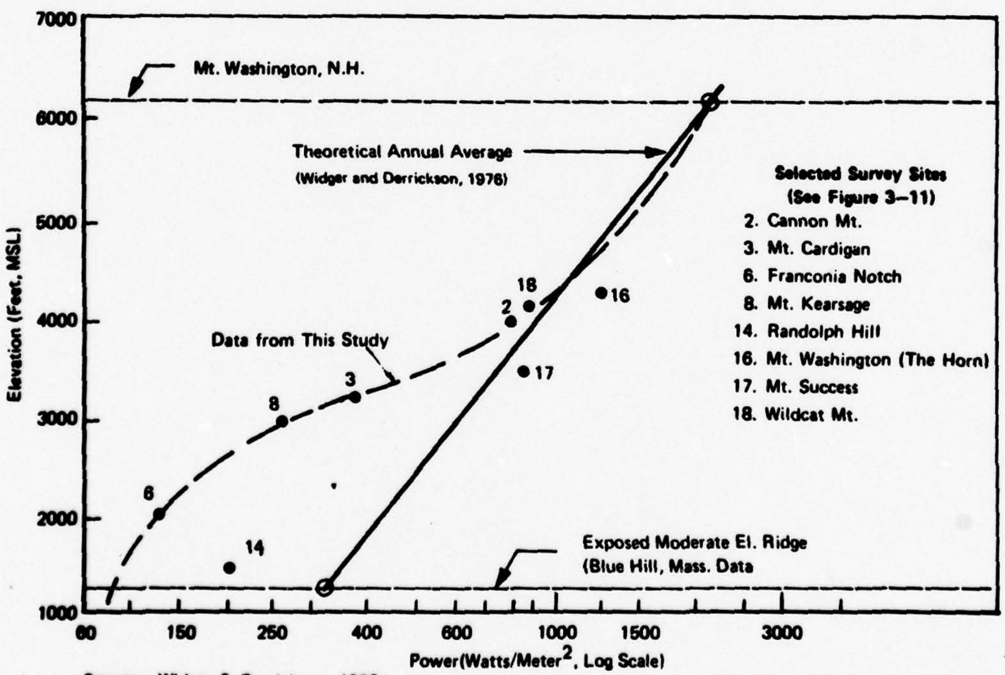
An additional study by Widger & Derrickson (1976) examined the relative merits of coastal versus mountain locations for wind power generating stations. Again, much use was made of long-term meteorological data from Mount Washington. Average monthly wind speeds are shown on Table 3-6 based on 28 years of data. As noted above (Section 3.2.2) this is in excellent agreement with the results of this project.

Using their procedure, Widger and Derrickson (1976) produced estimates of the mean monthly theoretical wind power for Mount Washington. They showed that the monthly power varies between 5500 W/m^2 in winter to 1200 W/m^2 in summer. This pronounced variation agrees with the results discussed in Section 3.2.2 which show that a large amount of energy is available in the highly variable winter-time winds on the summit.

Figure 3-10 represents Widger and Derrickson's estimate of the annual average theoretical wind power to be expected in northern New England as altitude increases on well-exposed summits and ridges along with estimated values developed during the study reported herein. Blue Hill, Massachusetts data was used to establish the low end of the curve, Mount Washington data established the upper end. With only two stations available, they interpolated linearly for want of any other definitive guidance (Widger & Derrickson, 1976). It is difficult to judge the relative merits of this technique because of the extreme paucity of reliable wind data in the altitude range between 610-1525m (2000-5000 feet).

TABLE 3–6
MONTHLY AVERAGE WIND SPEED
MOUNT WASHINGTON
(1948–1975)

Month	Wind Speed m/s	(mph)
January	19.6	43.8
February	18.6	41.5
March	17.2	38.4
April	15.2	34.0
May	12.3	27.5
June	11.7	26.1
July	11.0	24.7
August	11.3	25.2
September	12.4	27.7
October	14.2	31.7
November	16.1	36.0
December	18.1	40.4
Annual	14.8	33.1



Source: Widger & Derrickson, 1976.

FIGURE 3–10 AVERAGE THEORETICAL WIND POWER, EXPOSED NORTHERN NEW ENGLAND RIDGES AND SUMMITS

For the site surveys a number of key qualitative parameters were identified as important to WT installations (see next section) and ranked for each site visited. The prime reason for the site visits was, however, to study the trees as indicators of ice damage, prevailing wind flow, and long-term wind energy potential. Most of the trees examined during these surveys were Balsam Fir, while it was occasionally necessary to study red spruce and white pine.

A calibration of the Griggs-Putnam Index in terms of mean annual wind speed for trees of the genera Abies (fir), Picea (spruce) and Pinus (pines) has recently been developed. Most experience with these genera has been with species found in the Northwest. The calibrations of indices of deformation for these genera are based on a very small data set. Therefore, at this point the predicted speeds using the Griggs-Putnam Index (which is felt to be more accurate than other indices) are being used as means for ranking sites rather than as an absolute measure of the mean annual wind speed.

It is recognized that caution must be used in ranking sites and interpreting wind velocities which are predicted using wind-flagged trees. The strongest winds occur during the winter, while the trees respond more strongly to growing season winds. Strong winds during the non-growing season will kill buds, break off branches, cause leaf abrasion, windward side root disruption and a redistribution of plant hormones. All of these effects will result in a change in the tree morphology and anatomy the following growing seasons. Trees examined during the winter time will look more flagged than they will at the end of the following summer. Also, the lack of wind flagging does not mean there is no wind. Balsam Fir show little wind effect below 13 mph which is a reasonable wind speed for wind power purposes. Trees in location where the winds may come from three or four directions with equal frequency will show little flagging. With these cautions in mind, it is felt that the techniques employed in the surveys provide a powerful, quick, inexpensive approach to site selection and evaluation.

Besides the Griggs-Putnam Index, two other indices of the amount of wind defromation are useable -- the Deformation Ratio and Compression Ratio. The Deformation Ratio has only been calibrated for the genera Pinus and Pseudotsuga. Attempts to apply it to Picea and Abies can result in confusion. The Compression Radio also has been calibrated only for the former two genera; however, it is felt that species or genera are less important factors affecting the development of wind-induced compression wood than such factors as tree age, slope and crown weight. Therefore, speeds are predicted for trees based on earlier calibrations of the Compression Ratio on Ponderosa Pine and Douglas-fir. The mean error for these predictions should be about ± 20% based on results for Ponderosa Pine and Douglas-fir. These other parameters were measured during this second survey, but are not reported because their applicability to the species studied has not been fully documented.

The site wind power estimates from this study which are shown in Figure 3-10 was developed using the site data summarizes in Table 1 of the Executive Summary section and the curve of annual wind power as a function of mean wind speed (Figure 3-9) developed by Widger (1976), the annual wind power from other mountains peaks was estimated. These values were then plotted on Figure 3-10. The data for sites 1 through 5 show good agreement with Widger's estimate of available wind power as a function of altitude. Site 6, Randolph Hill, may be low because the White Pine used to establish the Griggs - Putnam index is a species that has been calibrated only for the Northwest and may have to be recalibrated for Eastern conditions. Evidence of ice or severe wind damage to the trees was indicated at both sites 7 and 8 which may influence the resultant interpretation. The dashed curve in Figure 3-10 is an estimate of the avaiable wind power as a function of elevation using data developed in this study and the approach described above.

3.8 Wind Site Surveys

Two wind prospecting field trips were conducted in New Hampshire as part of this project. The purpose of the field trips was to visit specific sties identified by examining contour maps, conducting interviews, and conducting an aerial and photographic survey. These sites were identified as locations which might have good wind power potential and yet be reasonablly accessible to roads and powerlines. An effort was made to find land which might also be available for WT installations in the near future. At each of the locations visited various levels of analysis were made to further evaluate the wind power potential. The following sections outline the methodology used, the results obtained, and the conclusions drawn.

3.8.1 Site Prospecting Methodology

The first step in this wind survey was an analysis of existing summarized and unsummarized meteorological data. Wind data in New Hampshire are scarce and because of the rugged terrain, the wind patterns are complex,which results in the wind speed often varying by more than a factor of two over distances less than a kilometer. For this reason techniques were employed to estimate where the winds might be strong. The first such technique was to identify topographic features which are known to accelerate the wind. Thus a number of sites were chosen from an analysis of topographic and raised relief maps. A public survey of poeple such as meteorologists, foresters, ski lift operators and pilots was made to further identify areas known to be windy. An aerial reconnaissance survey in a light aircraft was next performed to identify accessible sites that appeared to have wind-deformed vegetation. This preliminary survey provided a distillation process from which sites were chosen for a brief, but more-detailed investigation.

3.8.2 Site Survey Nomenclature

During each site visit, and during a previous aerial survey, an estimate was made of following five qualitative parameters which are felt to be very important to assessing the viability of a candidate WT site:

(1) Proximity to Power Lines

(2) Site Areal Extent (or potentially useable land area)

(3) Land Availability (or land ownership influence and degree of restriction for WT installations)

(4) Land Accessibility (or nearness to roads that could be used for installation, maintenance, and service of WT's)

(5) Site Exposure (or openness of site to winds from all directions)

An attempt was made to employ these parameters along with an estimate of the annual average wind speed in developing a numerical ranking scheme for the sites studied. This task proved to be too lengthy and time consuming to be done with any degree of soundness within the resources of the contract.

The Tables to follow, which summarize the results of the site surveys, employ the following four qualitative descriptions for the above parameters:

- Poor
- Fair
- Good
- Excellent

Where available information was unclear, the parameter description was labelled Questionable. These descriptions are useful only for a relative ranking of site parameters at this point. The sites which are recommended from this study used the above parameters and descriptions to arrive at a subjective evaluation of potential WT sites. It is recommended that future wind studies pursue the development of a more objective and quantitative basis for employing these types of descriptors.

3.8.3 First Site Survey

The first on site survey employed only a visual examination of wind deformed vegetation. During this survey 14 sites were visited during which time trees were examined for species and photographed in order to estimate the Griggs-Putnam Index, G, for wind deformed vegetation (Wade et al., 1979). The tabular results of the first survey are summarized in Table 3-7 for the sites whose location is placed on the map shown in Figure 3-11.

Results

The results of the first survey indicate that none of the sites studies are of sufficient extent to support a large cluster of WT's even though many of them have excellent wind energy potential. Many sites did not exhibit trees with significant wind-induced flagging, but are mentioned so that future investigators will be able to use the negative results as well. Many sites are well exposed to winds and are on land that are potentially available for WT installations and would be reasonably close (order 1-2 km) to access roads and powerlines. From the first survey, the best potential sites are the following:

- Cannon Mountain (Franconia)
- Crotched Mountain (Francestown)
- Dixville Peak (Dixville)
- Little Attitash Mountain (Bartlett)
- Mount Martha (Whitefield)

In addition, Pine Mountain in Gorham represents a potential site of limited extent on which electromagnetic interference problems may exist with an existing television antenna.

3.8.4 Second Site Survey

The second and more detailed survey of ten sites consisted of an examination of wind-deformed vegetation and short-term anemometer measurements of wind speed. The wind speed measurements were related to data collected continuously at two reference stations: (1) the Mt. Washington Observatory, and (2)a 3-m high reference anemometer installed by this project on Kearsarge Mt. for the 3-day period of the survey. Mt. Washington represented a location with a long history of wind data. Because its elevation, 1,917 m (6,280 ft) is so much higher than the other seven sites, an additional base station was set up for comparison purposes at Kearsarge Mt., elevation 915 m (2,990 ft). With anemometer data from these two reference stations it was possible to examine the time rate of change of the whole wind field, correlate data with the passage of weather fronts, and ascertain whether the winds observed during the experiment were at a time when prevailing conditions obtained. Additional parameters evaluated in the second site survey were exposure, accessibility,proximity to power lines, land area availability;

Table 3-7

SUMMARY OF OBSERVATIONS

FIRST SITE SURVEY

SITE	TOWN	SITE SYMBOL ON APPENDIX A MAPS	PREVAILING WIND DIRECTION	GRIGGS-PUTNAM INDEX, G*	TREE TYPE	ESTIMATED ANNUAL $\overline{V}$, m/s (mph)	PROXIMITY TO POWER LINES	SITE AREAL EXTENT	AVAILABILITY OF LAND	LAND ACCESSIBILITY	SITE EXPOSURE	COMMENTS
Cannon Mtn. (Main Ridge) (1240m)	Franconia	B-2	SE	3	Balsam Fir	8.1 (18.1)	Good	Fair	Good (State Park)	Good (via Tramway)	Good	Aerial Tramway to near Summit for Ski Area
First Cannon Ball (Cannon (1130m)	Franconia	Not Shown	SSE	No Obs. Flagging	--	--	Poor	Fair	Poor	Poor	Good	Within WMNF
Gap Between Cannon Balls (~1000m)	Franconia	Not Shown	SSE	~4	Note (1)	Not Available	Poor	Poor	Poor	Poor	Note (1)	Within WMNF
Crotched Mtn. (627m)	Francestown	B-17	WNW	3 (summit)	Balsam Fir	8.1 (18.1)	Good	Fair	Excellent	Good	Excellent	Abandoned Fire Tower, Micro-wave Antennas on Summit
Dixville Notch (670m)	Dixville	Not Shown	NW	No Obs. Flagging	--	--	Good	Poor	Excellent	Excellent	Good	Expect Accelerated Flow through Notch
Dixville Peak (1061m)	Dixville	B-4	NW	~2.5	Balsam Fir	7.3 (17.3)	Fair	Good	Excellent	Fair	Good	Ski Slope on North Slope
Mt. Gloriette (915m)	Dixville	Not Shown	NW	No Obs. Flagging	--	--	Good	Poor	Excellent	Good	Good	South Rim of Dixville Notch, Ice Damage Visible
Kinsman (North) (1330m)	North Woodstock	B-8	SE	~4	Balsam Fir	8.7 (19.5)	Fair	Fair	Fair	Poor	Excellent	Rough Terrain, Portion within Less Restrict-ed Part of WMNF
Little Attitash (768m)	Bartlett	B-1	W	3+ (near ski lift) 3 (ridge)	White Pine Balsam Fir	5.5 (12.3) 8.1 (18.1)	Good	Good	Fair	Excellent	Good	Ski Area, Summit within Restricted Portion of WMNF

Loon Mtn. (937m)	Lincoln	B-9	Not Available	No Appreciable Flagging	--	--	Good	Good	Questionable	Excellent	Good	Ski Area but not Restricted Area of MWNF
Mt. Martha (1219m)	Whitefield	B-10	ESE	2	Balsam Fir	7.4 (16.6)	Fair	Fair	Fair	Good (Jeep road)	Excellent	Fire Tower, within WMNF but Land not Severely Restricted
Pine Mtn. (733m)	Gorham	B-11	WNW	~2+	Balsam Fir	7.4 (16.6)	Excellent	Poor	Good	Good	Excellent	TV Station near Summit
Reed Brook Trail Powerlines (762m)	North Woodstock	Near B-16	Not Available	No Obs. Flagging	--	--	Excellent	Poor	Fair	Good	Poor	Within WMNF but Land not Severely Restricted

*Use following equation for fir trees: $\overline{V}$ (m/s) = .96G + 2.6 (Douglas Fir, Ponderosa Pine, White Pine)
$\overline{V}$ (m/s) = .65G (Balsam Fir)

Note (1) Not Defined

Arthur D Little, Inc.

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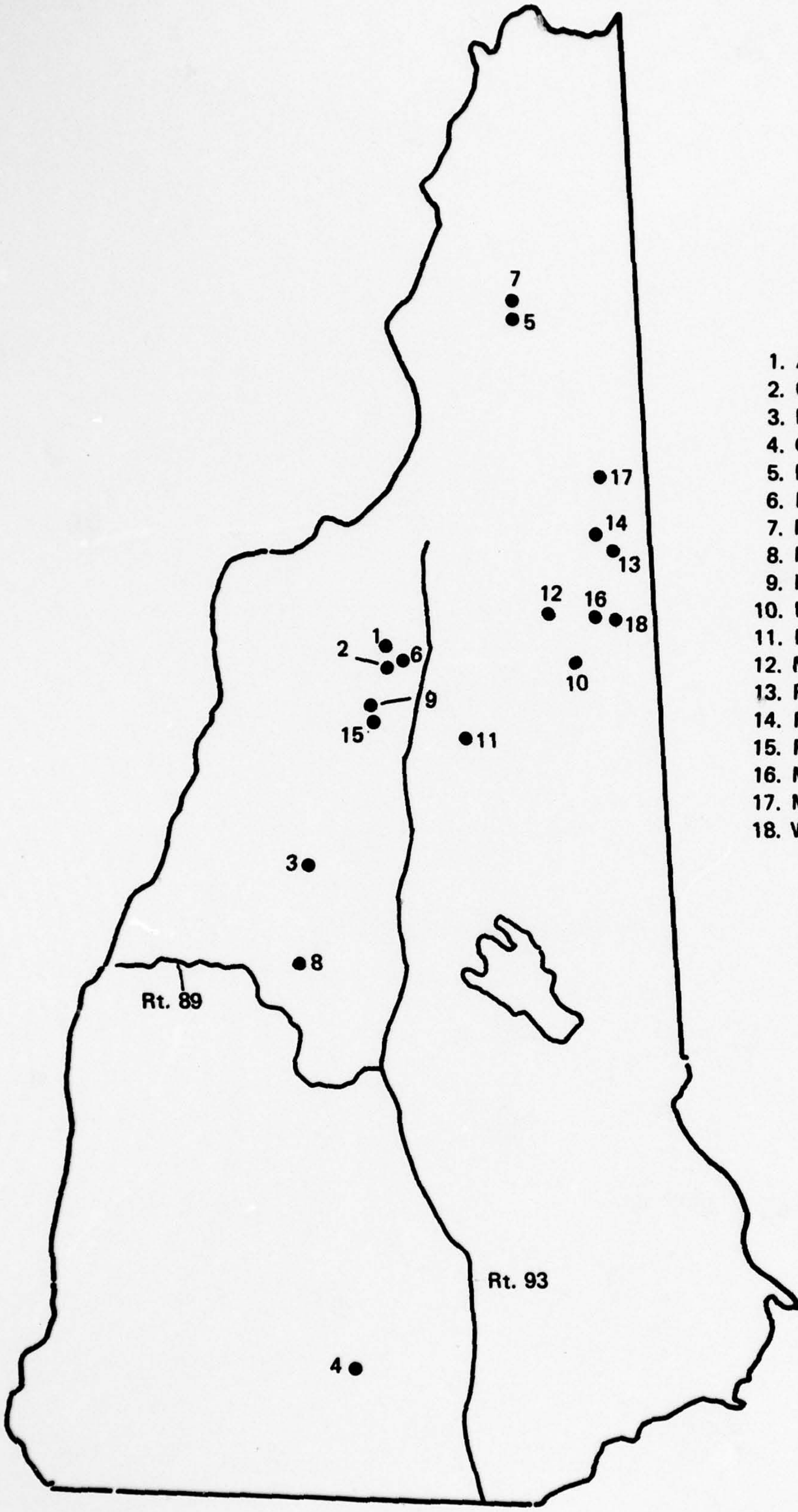


Sites Studied During Field Surveys

1. Artists Bluff/Bald Mt.
2. Cannon Mt.
3. Mt. Cardigan
4. Crotched Mt.
5. Dixville Peak
6. Franconia Notch
7. Mt. Gloriette
8. Mt. Kearsage
9. Kinsman Mt.
10. Little Attitash Mt.
11. Loon Mt.
12. Mt. Martha
13. Pine Mt.
14. Randolph Hill
15. Reed Brook Trail Powerlines
16. Mt. Washington
17. Mt. Success
18. Wildcat Mt.

FIGURE 3–11 DATA SITES SURVEYED IN NEW HAMPSHIRE

and possible WT interference with radio, television, microwave, and aircraft beacon antennas.

At each site the available vegetation was examined, core samples from trees were extracted and photographs of the tree were taken. Most of the trees were Balsam Fir, Red Spruce or White Pine. Beech and Gray or Yellow Birch were also noted. As discussed in the previous section, the Griggs-Putnam Index, G, for wind deformed vegetation was used to estimate annual average wind speed only for ranking sites according to wind speed. In addition, the wind speed profile was measured at each site at which sufficient wind was available on that day to enable to TALA kite to be flown ($\sim$4.5 m/s min. wind speed required). The TALA kite measurements provided an estimate of the wind speed profile, direction, and gust intensity, I_G, defined herein by equation (3-6).

$$I_G = \frac{\sigma_v}{\overline{V}} \qquad (3\text{-}6)$$

In equation 3-6, σ_v is the standard deviation of the instantaneous wind speed measurements collected at 10 second intervals over a five minute period at each level and $\overline{V}$ is the mean speed for the same five minute period. The levels samples were 15, 30, and 60 m (50, 100, and 200 feet). These levels were chosen because they correspond to hub heights of small, medium and large WT's. Also calculated was the power law coefficient α given in equation (3-1). Wind velocities measured by the Kite were corrected for temperature and elevation measured at each site.

It should be recognized that while the above information is useful it represents only one "snapshot" in time of the vertical structure of wind at each site. The information can be best used as a guide to the relative aerodynamic smoothness of a site under the wind flow conditions experienced during the survey. Again the information should be used only as comparison and not as an absolute evaluation of the vertical wind structure.

Continuous measurements of wind speed at a height of 3 meters were made at each site visited. This information was collected for two reasons; one was to assess the time rate of change of wind speed during wind profile measurements and the other was to provide a means of comparing locations to the reference or base station, Kearsarge Mt., and to the historical data set, Mt. Washington. Mean wind speeds were measured at 3 m (10 feet) during the five minute period over which winds were measured at each of the three profile levels, 60, 30, 15 m (200, 100 and 50 feet). The wind speed at 3 m (10 feet) measured while the TALA kite was at 61 m (200 feet) was used as a reference. Wind speeds measured at 30 and 15 m (100 and 50 feet) were then corrected for temporal changes noted at the 3 m (10 feet) level. This procedure was adopted to prevent temporal wind velocity changes from

masking changes in velocity measured at the three levels in the vertical plane.

These results should be used with caution because the winds measured during the survey were rarely from the Northwest which is the dominant direction. The realtionships between sites under different wind directions will be different.

The anemometer data from both the Mt. Washington Observatory sensor and the anemometer installed on Mt. Kearsarge are presented in Table 3-9 for the period of the study. These data indicate the passage of a weather front during which time the wind was rarely from the prevailing direction at the reference stations (W and NW). This conclusion was borned out by local weather reports. This result was unfortunate for two reasons:

(1) It would be most useful to measure the wind profile shear exponent for wind flow over mountain summits when the wind is from the prevailing direction.

(2) When attempting to establish any correlations between various sites or stations based on limited test experience is most useful to perform this correlation when conditions are relatively stationary and ideally in their predominant flow pattern.

Due to the passage of the front the measured wind velocity on Mt. Kearsarge (height: 895m) was occasionally in excess of that simultaneously measured on Mt. Washington (height: 1917m). As a result no short-term velocity correlation could be drawn between the wind speeds at any locations. The reference data were very useful for this reason.

Results

The results of the second site survey are summarized in tabular form in Table 3-8. Data collected continuously at Mt. Kearsarge and Mt. Washington during the second site survey are shown in Table 3-9. A map depicting the locations of the sites visited in the second survey is presented in Figure 3-11. Related data are also presented in tabular form in Appendix C.

From the second site survey, the following list of additional sites are recommended for further study and the possible installation of anemometers. The towns in which they reside are included in parenthesis.

- Artists Bluff/Bald Mountain (Franconia)
- Randolph Hill (Randolph)
- Wildcat Mountain (Bean's Purchase)

Table 3-8

SUMMARY OF OBSERVATIONS

SECOND SITE SURVEY

SITE	TOWN	SITE SYMBOL ON APPENDIX A MAPS	PREVAILING WIND DIRECTION	GRIGGS-PUTNAM INDEX, G*	TREE TYPE	ESTIMATED ANNUAL $\bar{V}$, M/S (MPH)	ESTIMATED POWER LAW COEFFICIENT 30-60 M (1000200 FT)	PROXIMITY TO POWER LINES	SITE AREAL EXTENT	AVAIL-BILITY OF LAND	LAND ACCESS-BILITY	SITE EXPOSURE	COMMENTS
Mt. Cardigan (951m)	Alexandria	B-3	NW	2	Balsam Fir	7.4 (16.6)	.35	Poor	Fair	Excellent	Poor	Excellent	State Park. N-S Ridge-line for ~2km.
Franconia Notch (Northwest End) (550m)	Franconia	B-5	SE	2	Spruce & Beech	5.0 (11.2)	.11	Excellent	Poor	Good	Excellent	Good	On Highway 3. Receives out-flow of Franconia Notch.
Artists Bluff, Bald Mtn. (735m)	Franconia	D-1	SE	3.5	Balsam Fir	8.4 (18.8)	Not Measured	Good	Poor	Fair	Good	Excellent	Private land with ridge-line parallel to prevailing glow.
Mt. Kearsarge (895m)	Wilmot	B-7	NW	3	Red Spruce	6.2 (13.9)	.11	Poor	Fair	Good (State Park)	Fair	Excellent	Fire Tower and Microwave Antennas on Summit. State Park.
Randolph Hill (457m)	Randolph	B-12	NW	3	White Pine	5.5 (12.3)	Not Measured	Excellent	Good to Excellent	Excellent	Excellent	Fair	Low Elevation Site Receives Westerly Flows through Pass between Mountains.
Mt. Washington Summit (1917m)	Sargent's Purchase	A-1	WNW	No Vegetation	--	--	.15	Excellent	Poor	Poor	Poor on year-round basis	Excellent	Severely restricted. Severe ice and snow conditions and extreme winds.
Mt. Washington (The Horn) (1219m)	Sargent's Purchase	B-6	NW	7	Balsam & Spruce	10.7 (23.9)	.15	Fair	Fair	Poor	Poor on year-round basis	Excellent	On Summit Auto Road same as Fox Mt. Washing-ton.
Mt. Success (1073m)	Berlin	B-13	NW	3.5	Balsam Fir	8.4 (18.8)	.23	Poor	Fair	Excellent	Poor	Excellent	Logging Roads to within

												~3-4 km of Summit. Summit on Appalacian Trail (see Sec 5.2.2.3.1)
Mt. Success Outlook (945m)	Berlin	B-14	SE	3.5	Balsam Fir	8.4 (18.8)	Not Measured	Poor	Poor	Excellent	Fair	Fair	Suspect Lee Rotors from Prevailing NE Winds.
Wildcat Mtn. (1219m)	Bean's Purchase	B-15	NW	3	Balsam Fir	8.1 (18.1)	-.08	Good	Fair	Fair	Good	Good	Ski Slope with Gondola Lift. Limited Land Bordering WMNF.

*Use the following equations for the Griggs-Putnam Index, G" $\overline{V}$ (m/s) = .96G + 2.6 (Douglas Fir, Ponderosa Pine, White Pine)
$\overline{V}$ (m/s) = .65G + 6.1 (Balsam Fir)
$\overline{V}$ (m/s) = 1.2G + 2.6 (Spruce, e.g., on the Horn of Mt. Washington)

TABLE 3-9
MT. KEARSARGE AND MT. WASHINGTON WIND DATA

August 18, 1979

Time	Mt. Kearsarge Speed m/s	Mt. Kearsarge Speed (mph)	Mt. Kearsarge Direct	Mt. Washington Speed m/s	Mt. Washington Speed (mph)	Mt. Washington Direct.
0800	6.4	(14.4)	SW	3.6	(8)	SW
0900	6.2	(13.9)	SW	4.0	(9)	SW
1000				5.8	(13)	SW
1100				6.7	(15)	S
1200	5.6	(12.5)	S	6.7	(15)	S
1300	5.3	(11.8)	S	7.6	(17)	S
1400	4.3	(9.6)	S	6.7	(15)	S
1500	5.0	(11.2)	S	9.8	(22)	S
1600	6.1	(13.6)	S	8.9	(20)	S
1700	6.4	(14.2)	S	7.2	(16)	S
1800	6.6	(14.7)	S	6.7	(15)	S
1900	8.7	(19.6)	S	7.2	(16)	S
2000	9.1	(20.3)	S	7.2	(16)	S
2000						
to						
0700	7.6	(17.0)	S	9.4	(21.1)	SW-S

August 19, 1979

Time	Mt. Kearsarge Speed m/s	Mt. Kearsarge Speed (mph)	Mt. Kearsarge Direct.	Mt. Washington Speed m/s	Mt. Washington Speed (mph)	Mt. Washington Direct.
0730				8.9	(20)	W
0900	4.2	(9.3)	SW	8.5	(19)	W
1000	2.9	(6.5)	SW	9.4	(21)	W
1100	2.9	(6.6)	SW	7.2	(16)	NW
1200	4.4	(9,8)	SW	7.2	(16)	NW
1300	4.4	(9.8)	SW	5.4	(12)	NW
1400	1.5	(3.3)	SW	4.0	(9)	NW
1500	1.4	(3.1)	W	3.6	(8)	N
1600	0.9	(2.0)	W	4.0	(9)	N
1700	1.3	(3.0)	W	4.9	(11)	N
1800	1.4	(3.2)	W	6.7	(15)	NW
1900	1.4	(3.2)	W	6.7	(15)	NW
2000	1.4	(3.2)	W	4.5	(10)	NW
2100	1.4	(3.2)	W	4.0	(9)	NW
2200	1.4	(3.2)	W	4.9	(11)	NW
2300	2.5	(5.6)	W	1.8	(4)	NW
2300						
to						
0800	3.6	(8.0)			(12)	NW—N

August 20, 1979

Time	Mt. Kearsarge Speed m/s	Mt. Kearsarge Speed (mph)	Mt. Kearsarge Direct.	Mt. Washington Speed m/s	Mt. Washington Speed (mph)	Mt. Washington Direct.
0800	3.6	(8.0)		5.4	(12)	NW—N
0900	2.3	(5.1)	N	7.6	(17)	N
1000	1.7	(3.8)	N	5.8	(13)	N
1100	1.7	(3.9)	N	6.3	(14)	N
1200	2.0	(4.5)	N	8.9	(20)	N
1300	2.1	(4.7)	N	7.6	(17)	N
1400	2.5	(5.6)	N	7.6	(17)	N
1500	3.6	(8.0)	NE	6.7	(15)	N
1600	2.4	(5.4)	NE	6.7	(15)	N
1700	1.9	(4.3)	E	7.2	(16)	N

Mt. Kearsarge Average Wind Speed: 8.5 mph
Mt. Washington Average Wind Speed: 14 4 mph

FIGURE 3–12 WIND DEFORMED WHITE PINE AT RANDOLPH HILL TEST SITE

In this list, Randolph Hill looks most appealing because it has potentially the largest geographic extent for installing WT clusters of any of the sites visited. The main drawback to the site is the modest average windspeed of approximately 5.5 m/s (12.3 mph) estimated at the site examined at the right-angle turn of the Randolph Hill road in Randolph. The white pine tree on which the Griggs-Putnam Index, G, and Compression Ratio, C, (Wade et al., 1979) was measured is shown in Figure 3-12. It is felt that to the north and west of this point, the average wind speed might be greater than shown in Table 3-8.

The other sites recommended are felt to have a much larger annual average wind speed, but are not as extensive or as accessible. Wildcat Mountain in particular may be of very limited extent from the ridgeline east because it is on the border of severely restricted regions of the WMNF (see Figure A-2 overlays). Similarly, the Artists Bluff/Bald Mountain site at the northern outlet of the Franconia Notch is very small in extent, but appears to meet many other siting criteria.

The site at Mount Kearsage appears to be good except for drawbacks which may be major impediments to installing WT's. The site lacks a road for approximately the last .7 km and a powerline for approximately five or six km. There are also many microwave antennas on the summit, the signals to which may receive interference from WT blades. It may, however, be found in future tests that wood or composite blades do not pose a serious problem (Senior and Sengupta, 1978).

3.8.5 Other Sites Recommended

In the course of this study certain sites, primarily on mountains, were examined from nearby roads using vinoculars or by aerial survey. In addition, they were discussed with local residents where possible. Of these, the following four sites are of interest and should be studied further:

- Croydon Peak (Croydon, N.H., 848m height)
- Ossipee Mountains (Ossipee, N.H., 640m height)
- Pliny Range (Randolph, N.H., 1100m height)
- Red Hill (Mountonborough, N.H., 619m height)

Croydon Peak is a privately owned mountain with what appears to be a fair area available for the installation of WT's. A vast gently sloping area surrounding the summit has been burned off and, as a result, trees present no potential problem to WT installations. A summit fire tower could serve as a base for future measurements.

The Ossipee Mountains are privately owned lands on the leeward side of Lake Winnepesaukee and as such have excellent exposure. Generally speaking the perimeter of the range has fair accessibility to roads and powerlines. They exhibit a degree of wind flagging on the summit trees. On the eastern side, a ski lift is operated on Mt. Whittier providing accessibility to the summit of that portion of the range.

The Pliny Mountain Range is predominantly within the WMNF. The portion recommended is, however, south and west of the summit of Mount Starr King and outside the WMNF. This area is still at an elevation that could exhibit good average wind speeds. The site has a broad expanse of land, with good exposure to prevailing westerlies, is accessible by old logging roads in some areas, and at a fair distance from existing powerlines. This site is just west of the Randolph Hill site previously recommended. Wind flagged vegetation could not be discerned on the lower slopes of interest due to the extreme canopy of trees.

Red Hill is as large as many mountains discussed. It has a fair expanse of land available with a ridge aligned in a NW to SE direction. It is remote from roads and powerlines (fair to poor rating), but because of its private ownership, good exposure and expanse, it should have a future on-site examination. A remote examination of vegetation during this study indicated flagging on the western slopes, which indicates a prevailing easterly flow. It was felt that the indicated flow direction could also be caused by a shadowing effect on the eastern sides of trees caused by the presence of the summit.

4.0 PHYSICAL BARRIERS TO THE INSTALLATION OF WIND TURBINE GENERATORS

4.1 Icing

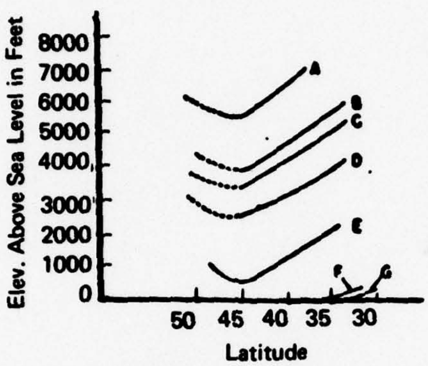
Ice accumulated on blades, towers, and transmission lines can cause hazards, add drag, and reduce the efficiency of wind machines. There are two types of icing, rime ice and glaze ice. Rime ice is drier, less dense, and therefore less hazardous than glaze ice; however, it can, over a period of time, build up large accumulations. Glaze icing, under certain conditions, can quickly accumulate on cold surfaces to thicknesses of several inches, which may not only reduce blade aerodynamic efficiency but constitute a severe safety hazard if suddenly released from a rotating blade. Such a problem may necessitate safety fences around all ice-susceptible wind turbine generator (WT) installations or an ice detector that limits machine operation when ice builds up to a certain thickness on the blades. In addition, thick accumulations of ice on all surfaces adds to overall profile drag loads which may impact machine life at survival wind speeds.

Definitive information on icing conditions in New England and the effect of icing on wind turbines is rather limited. Wegley (1978) reported on data gathered by the Association of American Railroads, Edison Electric Institute, American Telephone and Telegraph and other organizations on ice accumulation on transmission lines in the United States. The data presented in Wegley (1978) indicated that icing to thicknesses greater than 0.25 cm occurred between 3 and 11 times in northern N.H. over a 9-year period. The data, in general, are presented at such a macroscale as to be inappropriate for use in this study.

Putnam (1948) reported on a survey of available data over a 35-year period and prepared figures showing how the maximum icing would vary with latitude and elevation above sea level. They are reproduced here as Figures 4-1 and 4-2, respectively. It was recognized that ice deposits range in density from light frost through glaze ice. Using glaze ice as the standard, he showed that the maximum thickness of solid ice which might accumulate on stationary structures, increased with elevation from 12.7 cm (5 in.) at 610 m (2000 ft.) to 25.5 cm (12 in.) at 1220 m (4000 ft.). Using latitude 43° North and 3000 feet elevation as approximations of the situations in northern New Hampshire, Figures 4-1 and 4-2 suggest that somewhere between 7 and 9 inches of solid ice (perhaps more) could be expected under worst case conditions.

These general conclusions can be tempered with experience in some cases. Glidden (1979) has reported that severe icing conditions can be expected above 3600 to 3800 feet. Some instances of soft rime icing have been noted as low as 1700 feet. This information was obtained as part of the climatological research project discussed in Section 3.6 and partially reported by Glidden (1974).

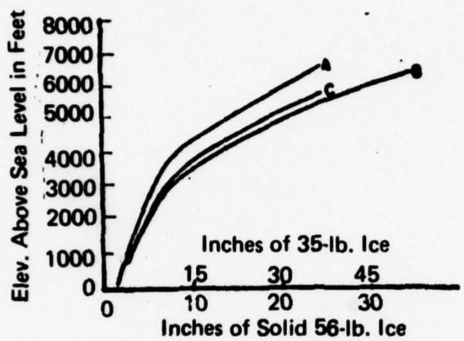
The technical community has not reported extensively on icing experiences with wind turbines. Linscott (1978) has described episodes of icing on the MOD-OA WT in Clayton, NM. In March of 1978 icing occurred on the blades. Site personnel first observed large pieces of ice, scattered on the ground, adjacent to the WT during operation. It was then observed that ice was shedding from the blades, while the blades were rotating. This situation posed a safety hazard for personnel and equipment. For



Curve A	36.0 inches
Curve B	18.0 inches
Curve C	13.5 inches
Curve D	9.0 inches
Curve E	4.5 inches
Curve F	2.5 inches
Curve G	1.0 inches

Source: Putnam, 1948

FIGURE 4–1 THE MAXIMUM THICKNESS OF 35-POUND ICE TO BE EXPECTED ON A STATIONARY STRUCTURE IN VARIOUS LATITUDES IN U.S.A.



Curve A	Latitude 58° ∞′
Curve B	Latitude 43° 45′
Curve C	Latitude 47° ∞′

Source: Putnam, 1948.

FIGURE 4–2 THE MAXIMUM THICKNESS OF ICE TO BE EXPECTED ON A STATIONARY STRUCTURE IN NEW ENGLAND

reasons of safety, NASA decided to provide an ice detector subsystem on the wind turbine. The control system has been modified to sense the ice detector signal and initiate a shut-down of the turbine. The MOD-OA ice detector system has, however, been found to be too sensitive and will be modified to avoid the unnecessary loss of many WT operating hours. At the present time, Reilly (1979) mentions that the MOD-2 WT should be able to survive with up to two inches of ice on all surfaces.

Putnam (1948) reports observing several inches of ice on the stationary structure several times. The maximum thickness observed on the rotating stainless-steel turbine blades was about 1.3 cm on the leading edge. As this skin of ice began to peel off, the unit would begin to run rough and was shut down. In general, though, it was concluded that in this experiment, blade flexure was adequate to promote ice shedding. Where possible this design feature should be incorporated on WT's for N.H. sites.

Owing to the sketchy nature of the limited information available, only tentative conclusions can be drawn. Episodes of icing can be expected at altitudes of 610 m to 1220 m (2000 to 4000 ft.). In the altitude range of interest, ice will build to several inches on stationary structures. Blades will acquire coats much less thick (1-3 cm) and may need to be shut down due to the safety hazard of ice and the attendant unbalanced loads on blades and transmission.

4.2 Interfacing the Wind Turbine Cluster with the Electric Grid

4.2.1 Interface Equipment and Controls

The equipment required to connect a wind turbine generator (WT) or cluster or WT's to a utility grid has been considered by numerous researchers (Linke, et. al., (1978); Kaman (1977)). In determining the feasibility and cost effectiveness of placing WT's in the mountains, it is sufficient to consider only the costs of presently available interface equipment, and the suitability of this equipment at proposed sites. The electrical interface for a WT consists of switchgear and protective relaying equipment, generator controls and indicators, a step-up transformer increasing the generator output voltage to line voltage, lightning protection equipment, and a source of emergency power for the WT installation, if required. At the proposed sites, changes in the generator controls and/or the lightning protection equipment are potentially required.

The experimental WT's, developed through funds provided by DOE and administered by the National Aeronautics and Space Administration (NASA), Lewis Research Center (MOD-0, MOD-OA, MOD-1, and MOD-2), as well as the WTG Energy Systems Inc. operating WT on Cuttyhunk Island, Massachusetts use micro-processors programmed to control generator performance. No problems in programming similar controls for the cut-in and rated velocities at any of the mountain sites are anticipated. However, problems exist in operating machines above presently used cut-out speeds. Section 4.5.3 estimates the power gained and discusses the control problems of increasing the present typical cut-out velocity of 20.1 m/s (45 mph) rated at the hub. As is discussed there, raising the cut-out velocity increases WT annual energy gain, but is not essential to realizing benefits from the high average

wind speed in the mountains. Therefore, changes in the controls are not essential and no increased cost for controls is anticipated.

4.2.2 Lightning Protection

Lightning protection for a WT is generally assured by providing good current paths through the outside surface of the nacelle and tower, thereby protecting the equipment inside. The blades typically carry a conductor, if they are non-conductive themselves (KAMAN, 1977). Transformers and the distribution line are protected by lightning arresters, controlled gaps that provide an almost complete path to ground. This protection requires in both cases an adequate ground, which may be difficult to achieve at rocky sites. For adequate protection, the resistance should be less than 50 ohms (Fink, 1968). This requires 3 m of rod embedded in the soil. In rock, costly drilled holes filled with low resistance cement around the conductor are required. Because this feature could be incorporated into the tower anchoring process, and not all sites are on bare rock, lightning protection for mountain sites is not generally expected to be appreciably more expensive than for low altitude sites. However, the site specific costs for lightning protection do pose small, but additional installation expense.

4.2.3 Costs of Interface Equipment

The costs of interfacing a WT with an electric utility arise from the equipment and the transmission lines. The equipment which consists of switches, transformer, lightning arrester, emergency power and controls etc., will cost approximately $33,300 plus $21 per installed kW (ADL estimate based on KAMAN, 1977 data). Transmission lines cost from $10,000 to $250,000 per mile, depending on terrain. For estimating, $45,000 per mile will be used. This figure was quoted by representatives of Public Service of New Hampshire (PNH) and, therefore, is believed to be the most reliable. Of this, $5,000 is the approximate additional cost to render a power line right of way passable by vehicles; therefore, the $45,000 estimate includes both the power line and access cost (Ligon, et. al. (1976)).

The incremental addition to the dollar per kW cost of an installation arising from interface equipment is shown in Figure 4-3. Because the total cost of a WT will be nearly $1,000 per kW, small installations far from existing lines could have their cost increased by 25 to 50% by interface equipment costs. A 33 kV line can transmit 20 MW of power; even a 2 MW WT uses only a fraction of this capacity. These large fixed expenses encourage large WT installations, which reduce the cost per kW.

4.3 Construction in the Mountains of New Hampshire

The mountains of New Hampshire are not typically virgin wilderness. Many of the mountains have gondolas, ski lifts or roads to the top. Mt. Dixville Peak and Mt. Gloriette in Dixville, N.H. have a bulldozed trail leading to their summits. Abandoned logging roads, many unmarked on U.S. Coast and Geodetic Survey (USGS) maps, are not uncommon. The possibility of motore vehicle transport

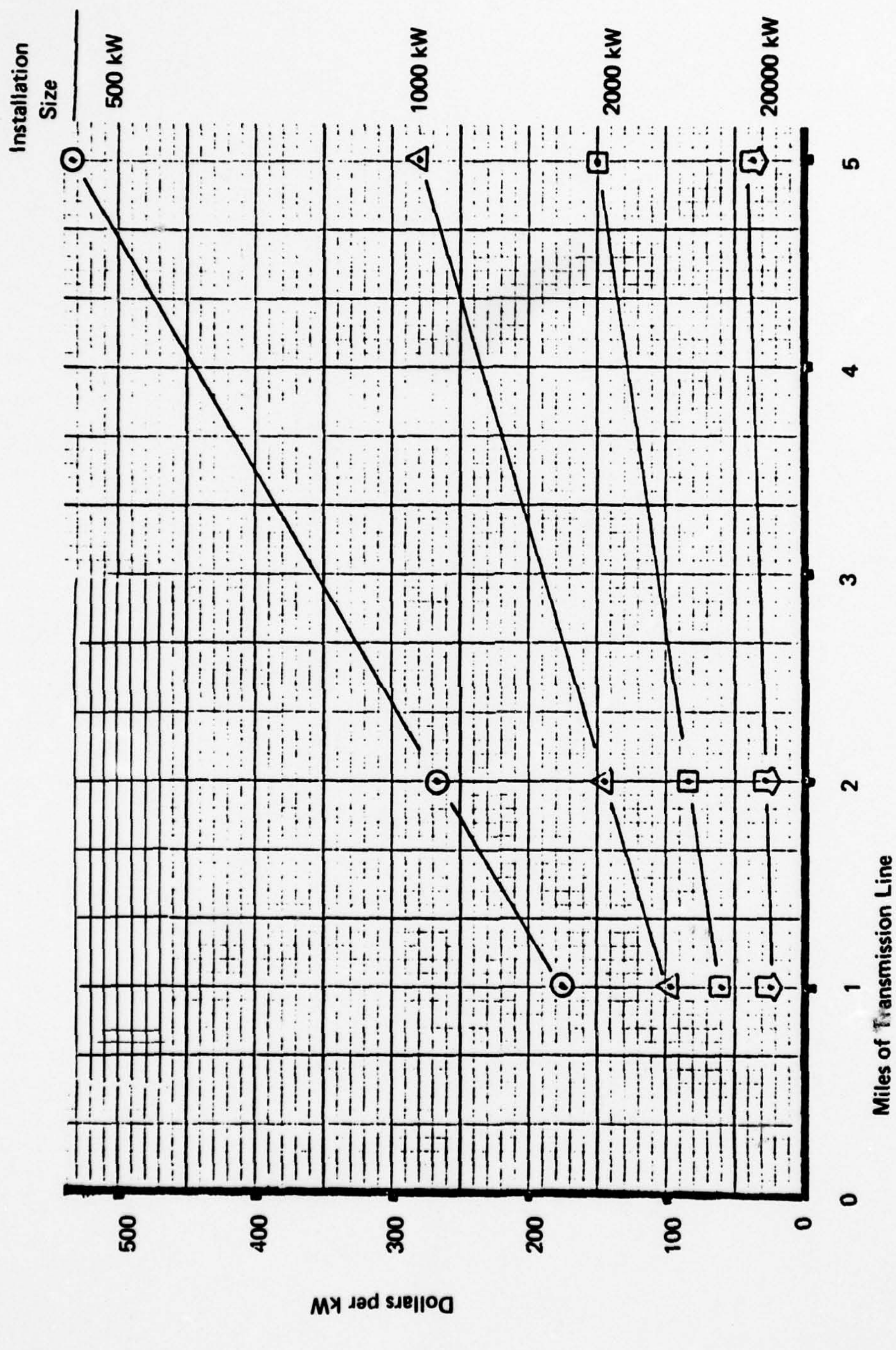


FIGURE 4–3 ELECTRICAL INTERFACE COSTS

is, of course, site specific, but access to potential sites may require only restoration of abandoned roads, or completion of already cleared rights of way. Construction may be delayed due to the persistance of snow or frequency of bad weather, but the existence of many ski slopes is testimony to the fact that mountain top construction in N.H. is reasonably routine.

For sites where motorized access is impossible, air lifting construction materials, equipment, and the WT is a real alternative. Table 4-1 presents the costs and capacities of helicopter crane service, and some representative component weights. Considering the incremental cost of $5,000/mile to render a power line right of way passable by motor vehicles and the still-limited load carrying capacity of such a road, air lifting may be preferred. It is, however, still necessary to routinely service and maintain WT's and therefore sites will generally require easy access by some means.

Using either a wilderness road (e.g., logging road) or helicopter service during construction will encourage clusters of medium scale WT models. Examination of Table 4-1 reveals that even the relatively small MOD-X 200 kw, wind turbine design would need to be broken down into components to be transported by helicopter. Thw weights of fully assembled components of the MOD-2 design (e.g., blades) exceed the lifting limits of helicopter cranes, but many of these components are modularized for transportation purposes. Even a sky crane could not, however, lift a MOD-2 gearbox. Therefore, it is felt that only small and medium scale WT's could be built using helicopters for component site deliveries.

4.4 Land Area Required

Land use is sensitive to the size of the zone around a WT which must be closed off. As a matter of safety, given that a full blade can be thrown 500 feet and a broken tip could go much further, a large area needs to be protected. Wind turbines running at higher rated wind velocities will also probably run at higher rpm, as the tip speed to wind speed ratio for best performance should not be changed. Therefore, potential blade throw distances will increase and safety areas may need to be enlarged. Second, it is felt that WT's cannot be too closely spaced or the WT's on the downwind side will receive less wind energy (i.e., wake effects). Figure 4-4 showing WT land use requirements is constructed using ten rotor diameters as the minimum spacing for wake effects and as the required distance of a safety fence from the perimeter of a cluster. It is interesting to note that the land use is approximately independent of the WT diameter. This results from the fact that power increases as a function of the rotor area (proportional to the diameter squared) while the land area used is also proportional to the square of the diameter. Land availability will not, therefore, discourage the use of a cluster of small WT's based on this type of analysis.

As an example, the summit of Mt. Success was estimated to be 1,000 by 500 feet during a site visit. Probably, not more than 300 kW of capacity can be installed if visitors to the summit are to continue to be allowed. Large arrays consume large areas and New Hampshire mountain

Table 4-1

SUMMARY OF HELICOPTERS USE FOR REMOTE WT CONSTRUCTION

COSTS:

Mobilization Fee to NH

$3000 for a Sikorsky S58
$5000 for a Sikorsky S61
$50000 for a Sikorsky Sky Crane

Hourly Cost

$ 700/Hr.	:	S58
$ 900/Hr.	:	S58 Turbo charged
$2000/Hr.	:	S61
$8000/Hr.	:	Sky Crane

CAPACITY:

MODEL #	AT 4000'		AT 4000', 90°F		AT SEA LEVEL	
	KG	LBS.	KG	LBS.	KG	LBS.
S58	5,300	(2400)	4,400	(2000)	8,800	(4000)
S58-T	6,600	(3000)	5,512	(2500)	11,000	(5000)
S61	10,600	(4800)	8,800	(4000)	17,600	(8000)
Sky Crane	24,200	(11000)	19,800	(9000)	39,700	(18000)

REQUIRED CAPACITY:

	ROTOR		GEARBOX		GENERATOR		TOWER	
	KG	LBS.	KG	LBS.	KG	LBS.	KG	LBS.
MOD-X	30,400	(13800)	30,400	(13400)	30,400	(13400)	9,900	(45000)
MOD-2	374,000	(169600)	86,000	(39000)				

SOURCE: Interview, Mr. Tim Wright, Keystone Helicopter, West Chester, PA.

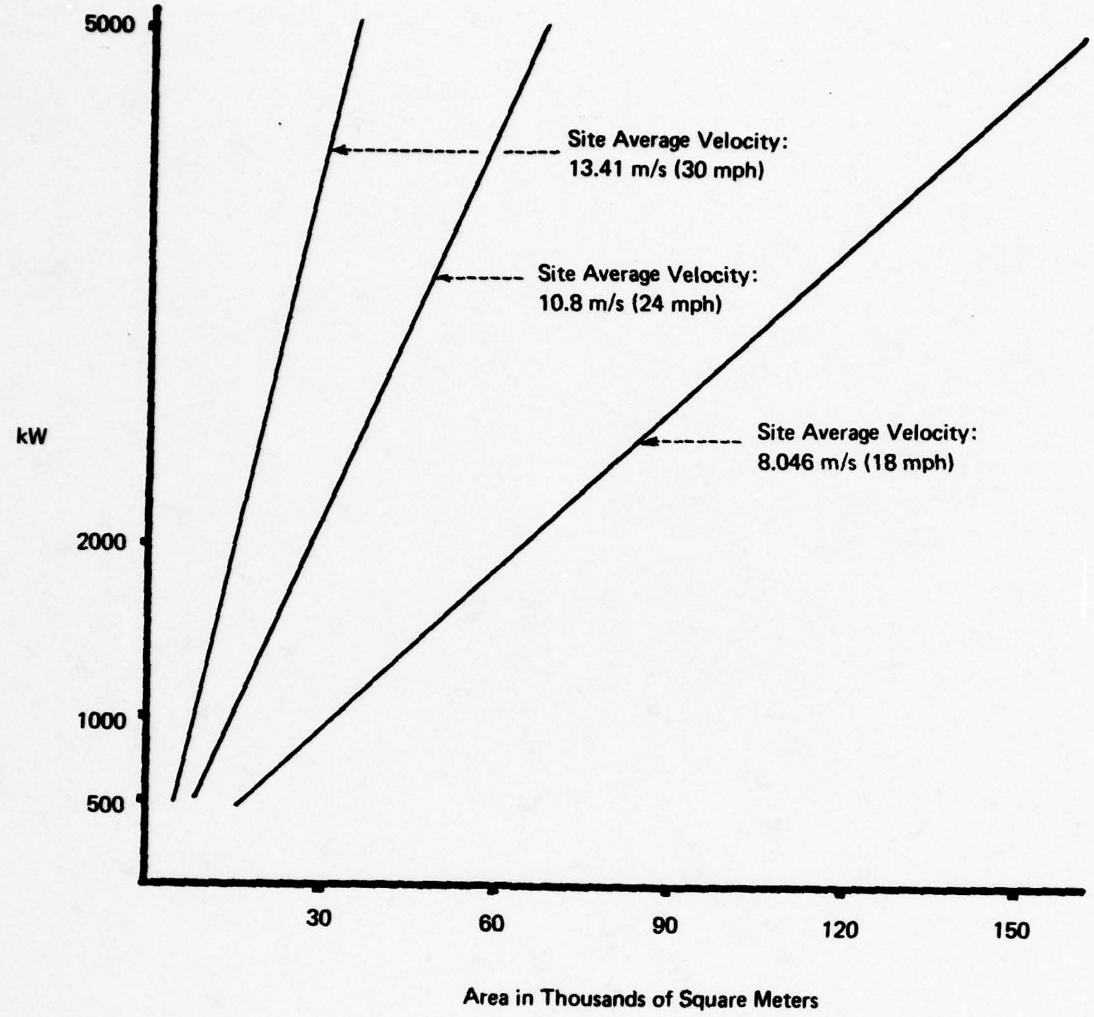


FIGURE 4–4 LAND AREA REQUIRED VS. INSTALLATION SIZE

peaks are not typically large flat expanses. The effect is to encourage placement of WT clusters along ridges, particularly if they run at right angles to the predominant wind. NASA, however, does not fence off a ten rotor diameter square around a large WT, because they feel that the machine safety system will shutdown the WT before it risks throwing a blade or chunks of ice. It is felt in this report that future cost effective WT's will, however, not have all of these safety systems and therefore casual visitors should be discouraged from being within the safety zone. As a result, it is felt that most N.H. mountain top WT installation will be of limited size. Even two MOD-2 WT's on most N.H. mountain tops would have badly degraded performance due to close spacing. One MOD-2, with 2500 kW maximum output, will not benefit so much from elevated average wind speeds as to justify more than a few miles (less than five) of 33 KV transmission lines. In order to better justify a few miles of new transmission lines, sites for WT clusters of many megawatts (> 10) of installed capacity should be sought.

4.5 Extreme Winds

This section presents estimates of the costs of strengthening existing WT's to survive greater wind loads. Electric power ratings are also estimated, and the results are expressed in dollars per kW. As average wind speeds rise, it is possible to design machines with lower cost per kW. However, placing machines in these high wind regimes will not be desirable if increased construction costs raise the cost per kW to a figure greater tnan the cost per kW of a more accessible machine in a lower wind regime.

4.5.1 Probability of Occurrence of Extreme Winds

The components of a WT are built to withstand the most severe loading conditions to which they will be exposed. Generally, where wind induces the loading, under laminar flow conditions the maximum loading occurs at the maximum wind speed. Therefore, knowing the maximum wind speed is necessary to design a WT.

Statistically, to define a maximum wind speed requires choosing the desired degree of certainty that this maximum will not be exceeded in some period of time. For estimating a design wind velocity a WT anticipated lifetime of 20 years is assumed, although WT cost studies generally use a 30-year life. Requiring with "P" percent certainty that V, any hourly velocity, will be greater than V_d, the maximum or design velocity, zero hours in 20 years establishes the following equation for V_d:

$$V_d = (-\ln(1-P^{1/20 \cdot 8760}))^{1/K} \cdot C \qquad (4\text{-}1)$$

where:

K = Weibull shape parameter for wind speed distribution

C = Weibull parameter of wind speed distribution equal to $\overline{V}/\Gamma\,(1 + 1/K)$--

$\overline{V}$ = the average wind velocity

Γ = gamma function.

The value of K is site specific; the value of P should be set with consideration given to the costs of strengthening the machine and the costs of repairing high wind damage. Given K and P,

$$V_d = \alpha \cdot \overline{V}$$

where: α is a constant, equal to

$$((-\ln(1 - P^{1/20 \cdot 8760}))^{1/K})/\Gamma(1 + 1/K) \qquad (4\text{-}2)$$

Table 4-2 gives α for various values of P and K.

The importance of α is this: given K and P, the maximum design wind speed is a constant times the average site velocity. Table 4-2 presents α from empirical sources at various sites (data from Ball, et. al. (1978)).

In determining the required strength of WT components at higher average wind regimes, the maximum design velocity has been taken to be at least seven times the average velocity, reflecting both the analytic and empirical α.

4.5.2 Effects on Operation and Maintenance Cost

Operation and maintenance costs can be expected to increase for a WT located in the mountains. This will be due, primarily, to the remoteness of the installation, not the extreme winds. However, greater stresses will probably lead to shortened component life, reflected in the estimated increase in replacement parts cost.

NASA, in estimating O&M costs for the MOD-X advanced WT design, itemized annual costs by functions (200 kW WT Conceptual Design Study, NASA (1979)). They estimated annual O&M at 2.6% of initial capital expense. Examining their estimates, allowing extra travel time, and requiring that at least two men are present during visits to remote sites, suggests that an increased allowance of 3.9% of initial capital cost be made. Table 4-3 presents these estimates.

4.5.3 Choice of Cut-Out Velocity

Most WT's are designed to stop the machine and feather the blades when the wind speed exceeds the cut-out velocity. The cut-out speed chosen influences the annual energy production, the controls, and the required strength in the blades and tower.

4.5.3.1 Annual WT Output

The effect on annual energy production (i.e., annual average power) arises because raising the cut-out velocity extends the number of hours that the WT will run at its rated power. This is expecially true for sites with many hours of wind velocity above the normal WT cut-out speed. An adequate approximation to the annual average power output from a WT is:

Table 4-2

SITE MAXIMUM WIND SPEED ESTIMATE

Maximum Wind Speed (1 Hour Average in 20 Years)
Given P: Desired Probability of Not Exceeding the Maximum Wind Speed and
Given K: Weibull Distribution Shape Parameter

Maximum Wind Speed (in 20 Years) = $\alpha \cdot$ Average Wind Speed

α =	P = .999	P = .99	P = .95
k =			
1.4	8.186	7.46	6.93
1.7	5.65	5.23	4.03
2.0	4.35	4.08	3.87

EMPIRICAL α

Mt. Washington, N.H.	5.1	San Gorgonio, Calif.	7.4
Ludington, Mich.	5.0	Boone, N.C.	7.0
Huron, S.D.	6.9	Montauk, N.Y.	6.7
Russell, Kansas	6.8	Mt. Tom, Mass.	6.5
Boardman, Oregon	11.2 *	(Ball, 1978)	

* 4.4 m/s (9 MPH) Average Wind

TABLE 4-3

OPERATION & MAINTENANCE (O & M) COSTS

ACTIVITY	NASA (1979) ESTIMATES	SEVERE CONDITIONS ESTIMATES
Routine Operation	1008	1008
Routine Maintenance	672	1344
Emergency Maintenance	672	1344
Annual Maintenance	448	896
10-Yr. Maintenance	448	448
Parts	750	1000
TOTAL	3998	6040
% of Capital Cost	2.6%	3.9%

Annual Average Power Output (kW) =

$$[\text{Rated Power (kW)}] \cdot (.5[EXP(-(V_i/C)^K)+EXP(-(V_r/C)^K] - EXP(-(V_c/C)^K) \quad \text{(Eq. 4-3)}$$

where:

V_i = Cut-in velocity

V_r = Rated velocity

V_c = Cut-out velocity

K,C = Weibull parameters for wind speed distribution at site.

Table 4-4 gives examples of the effect of varying cut-out speed. For Mt. Washington, with an annual average wind speed at hub height of approximately 17.88 m/s (40 mph), annual kWh (i.e., annual average power x 8760 hours) output would rise nearly 30% if the cut-out velocity were raised from 20.11 m/s (45 mph) as found on the MOD-2 design to 27 m/s (60 mph). The MOD-X conceptual design project assumes a cut-out of 22.35 m/s (50 mph); raising V_c to 27 m/s (60 mph) adds only 14% more annual output.

Note, though, that raising the cut-out velocity at less energetic sites than Mt. Washington is not as valuable. A MOD-X in a 13 m/s (30 mph) average hub height wind speed regime would gather only 4% more energy with an increased cut-out of 27 m/s (60 mph). As later generation wind turbines are built, the cut-out speeds may be allowed to rise, for those few energetic sites that are accessible to roads and power lines. Most present machines with 20 m/s (i.e., 45 mph) cut-out speeds do not, however, lose an unacceptable quantity of energy on typical New Hampshire mountain peaks sites below 1070 m (3500 feet) where annual average wind speeds are below 8.9 m/s (20 mph).

Figures 4-5 and 4-6 portray the potential energy output of two second generation WT designs funded by DOE/NASA (MOD-X and MOD-2, respectively) if placed on Mt. Washington. Data for the DOE/NASA MOD-OA, a 200-kW engineering prototype, about which a lot is known, is displayed in Figure 4-7. All data are developed using 1976 hourly average wind speeds as measured at the Mt. Washington Observatory. In the Mt. Washington wind regime, the machines achieve a plant factor (actual annual energy production/annual energy production if continuously operated at rated power) of between .28 and .62. Specifically, estimated plant factors are:

EXPECTED PLANT FACTORS ON MT. WASHINGTON

MOD-X =	.51	'Cut-out' Wind Speed:	22.4 m/s
	.62	'Cut-out' Wind Speed:	26.8 m/s
		All cut-out speeds measured at hub height.	
MOD-2 =	.28	'Cut-out' Wind Speed:	20.1 m/s
	.48	'Cut-out' Wind Speed:	26.8 m/s

Table 4-4

EFFECT OF THE CUT-OUT VELOCITY
ON PLANT FACTOR*

Cut-Out Wind Speed At Hub Height		20.1 M/S (45 MPH)	22.4 M/S (50 MPH)	26.8 M/S (60 MPH)	% Increase V_c = 20.1 to 26.8 M/S	% Increase V_c = 22.4 to 26.8 M/S
Average Wind Speed At Hub Height						
M/S	(MPH)					
8.9	20	.310	.312	.312	+ .6 %	> .1 %
11.2	25	.425	.435	.441	+ 3.76 %	+ 1.38 %
13.4	30	.493	.521	.544	+10.34 %	+ 4.4 %
15.6	35	.514	.561	.611	+18.87 %	+ 8.9 %
17.9	40	.502	.565	.645	+28.49 %	+14.6 %
20.1	45	.473	.545	.649	+37.21 %	+19.08 %

Notes:

-- Based on V_i = 6.26 M/S V_R = 12.29 M/S K = 2 C = 1.13 · (Average Velocity)

-- If V_c unlimited, plant factor would be .702 at 17.9 M/S Average Velocity

-- Based on ADL calculations

-- Annual Plant Factor = Annual Energy Production (kWh)/Rated Power x 8760

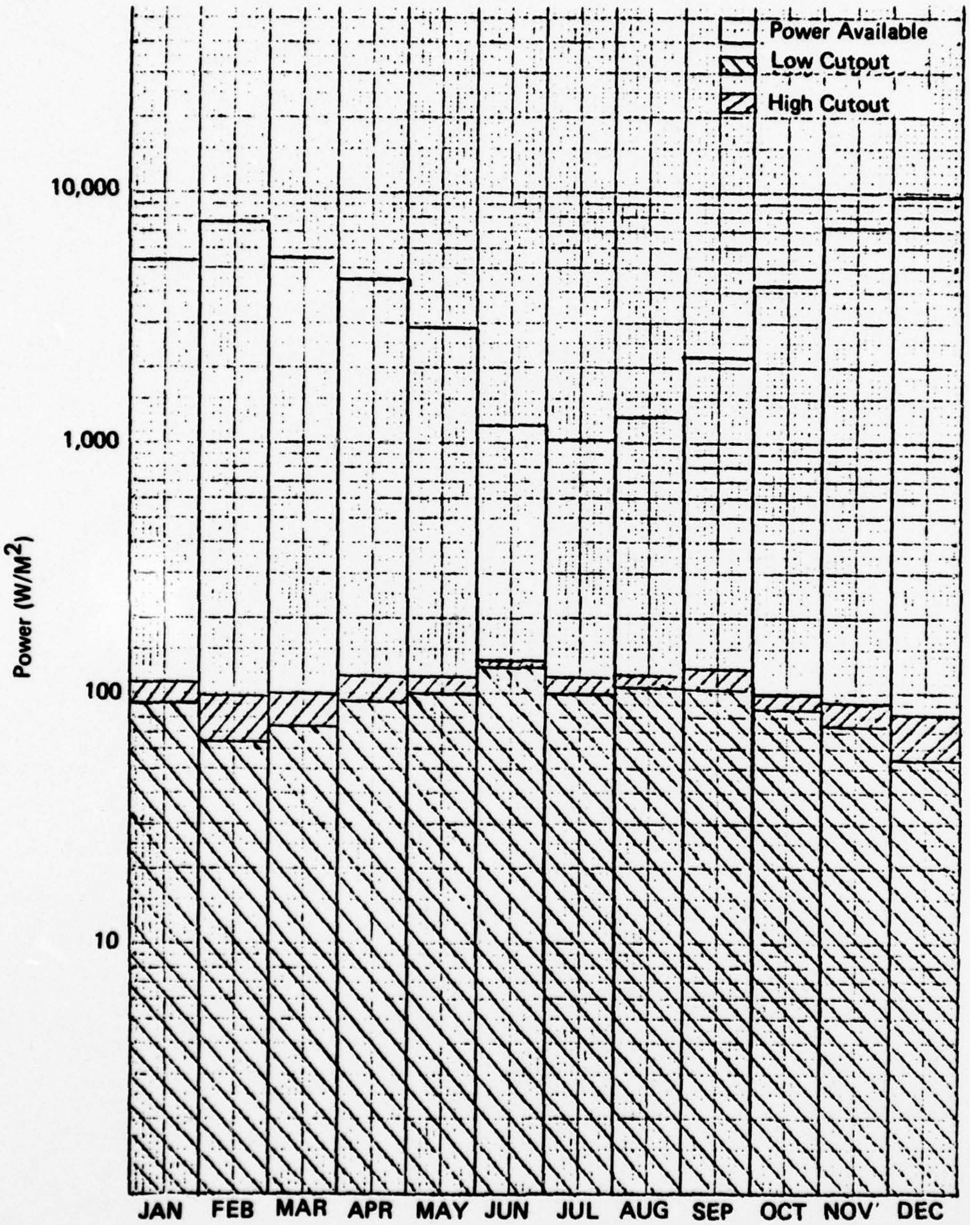


FIGURE 4–5 POWER OBTAINABLE FROM MOD X (1976)

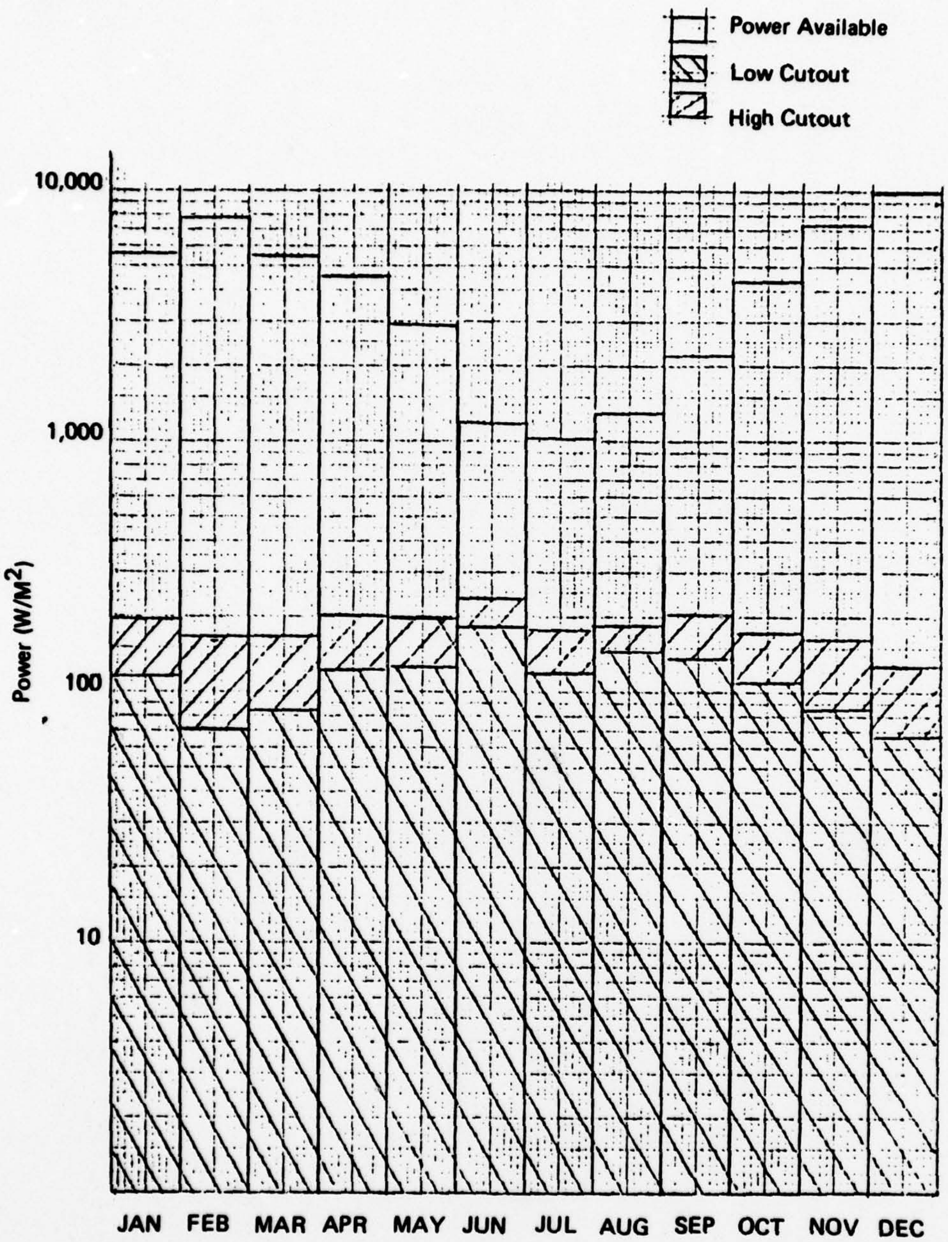


FIGURE 4–6 POWER OBTAINABLE FROM MOD-2 (1976)

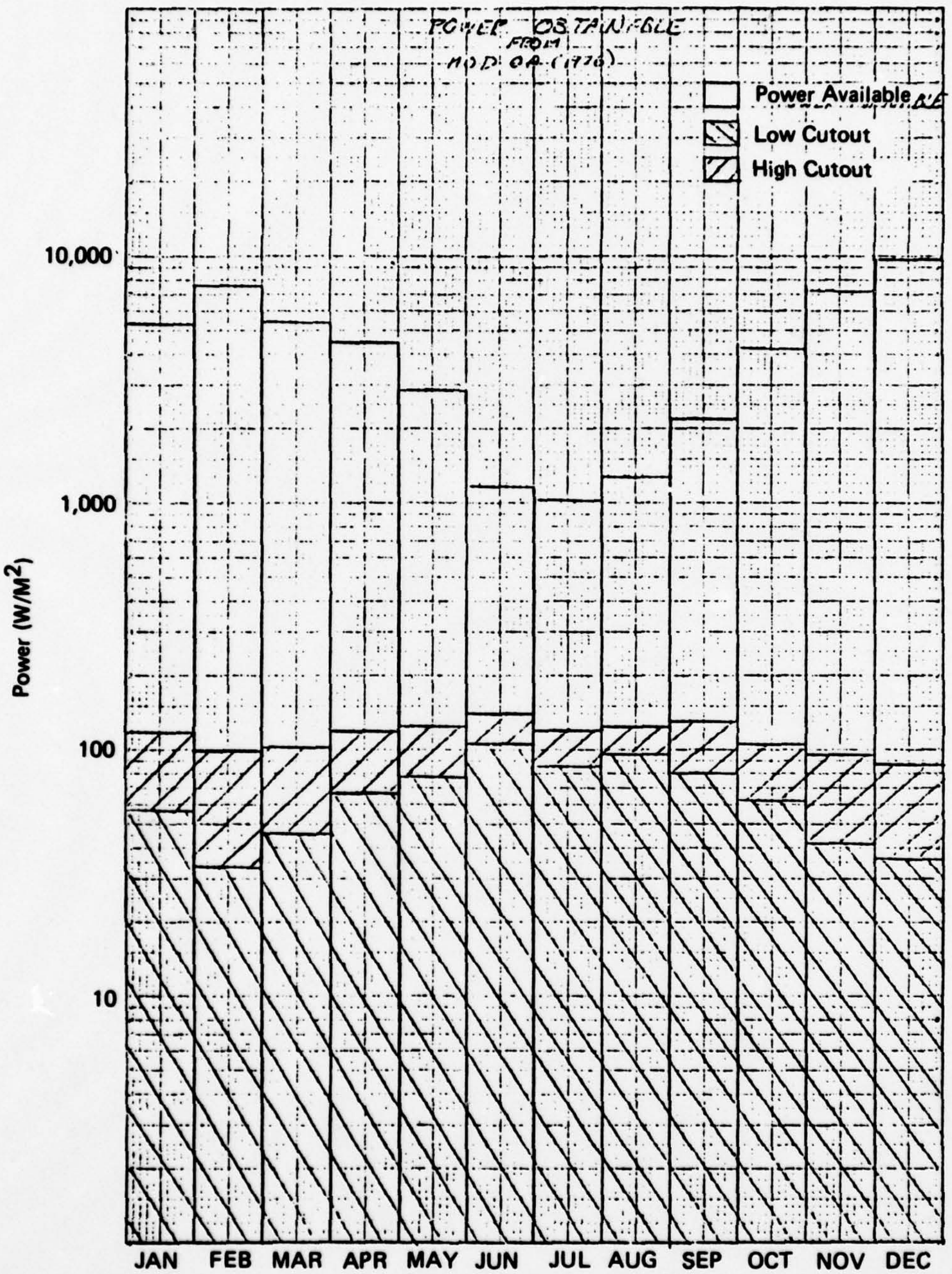


FIGURE 4–7 POWER OBTAINABLE FROM MOD-OA (1976)

The MOD-X, with a plant factor of .51 in the Mt. Washington wind regime, has realized only a few percent improvement in annual output over the NASA design study projection of .49 at a 6.3 m/s average annual wind speed site. Figures 4-6 through 4-7 are particularly interesting as they suggest that the power generation available on Mt. Washington rises in the summer, even though the power in the wind is greatest during the winter months. Figures presented in Appendix B containing monthly wind data summaires indicate way. During the summer months, the wind speed frequency distribution clearly indicates that more hours are available during which the wind speed is between the cut-in and cut-out velocities. Figure 4-8 is the annual summation of the monthly figures presented in Appendix B. The data points are the observed frequency of given wind speeds. The smooth curve is a computer generated graph of the best fit Weibull distribution through the data. A machine optimized for Mt. Washington would be better able to use the high winds, and would have a higher rated velocity than the unmodified MOD-X or MOD-2.

Both analysis and calculations from hourly wind data demonstrate that raising the cut-out velocity does not dramatically improve the annual energy production of a WT in high wind regimes. The plant factor curve presented by Cliff (1977) and reproduced here as Figure 4-9 indicates the reason. On Mt. Washington, the average wind speed is high enough that the ratio of the average wind speed (16 m/s (36 mph) at a 9.1 m height) to the rated wind speed (8.9 m/s (20 mph) for the MOD-2 and 7.6 m/s (17 mph) for the MOD-X at 9.1 m) is above 1.5--the limit of the curve in Figure 4-9. Although the curve does not cover these values, it does demonstrate that there is a maximum plant factor associated with any cut-out to rated wind speed ratio, and that either the MOD-X or MOD-2 designs would be operating beyond this maximum on Mt. Washington.* In order to realize the benefits of a high wind regime, better strategies are available than raising the cut-out velocity, as discussed in the Section 4.5.4.

4.5.3.2 Controls at High Wind Speed Locations

At present, long-term experience with WT's in high wind regimes is limited. WTG Energy Systems, Inc., has a 200-kW machine in Cuttyhunk Island, Massachusetts which is frequently exposed to high wind speeds. Their experience indicates the degree of difficulty in maintaining acceptable synchronization between the WT output and line voltage at high wind speeds with gusts (personal communication). Their design was a fixed pitch blade and controls speed by varying the electrical load on the WT. They make the point that this control approach is very useful in small or isolated grids (like isolated islands) where the WT output could be a large percentage of grid demand. They also feel that these locations are where WT's can be cost competitive very soon because of the present costs for conventionally-generated electricity.

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*Cliff's assumed probability density function for wind speed is different from that assumed in Table 4-4, and both are different from the actual distribution. The numerical values here are suggestive, but not exact. The conclusions drawn, however, are independent of the exact probability density function chosen.

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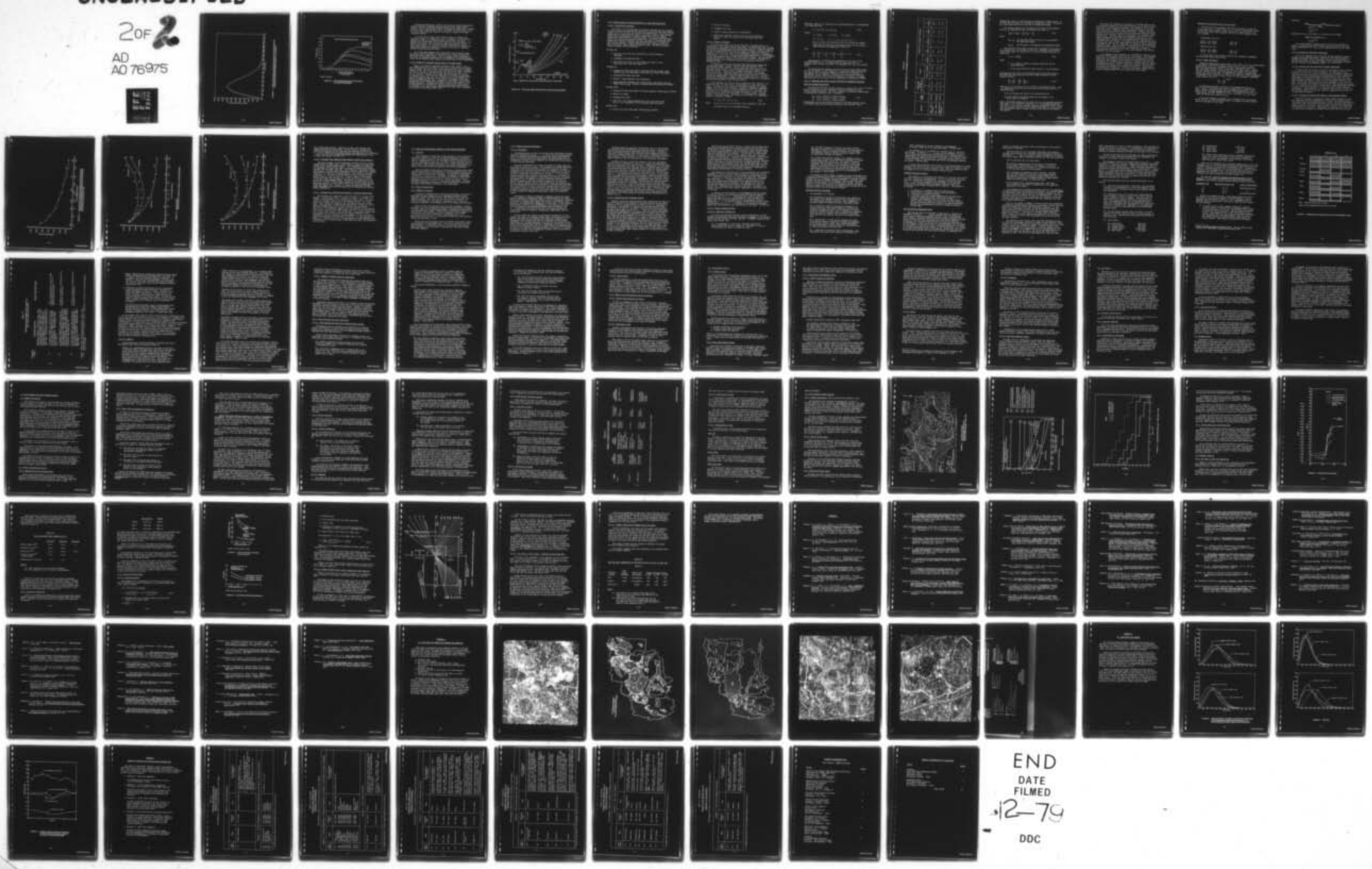

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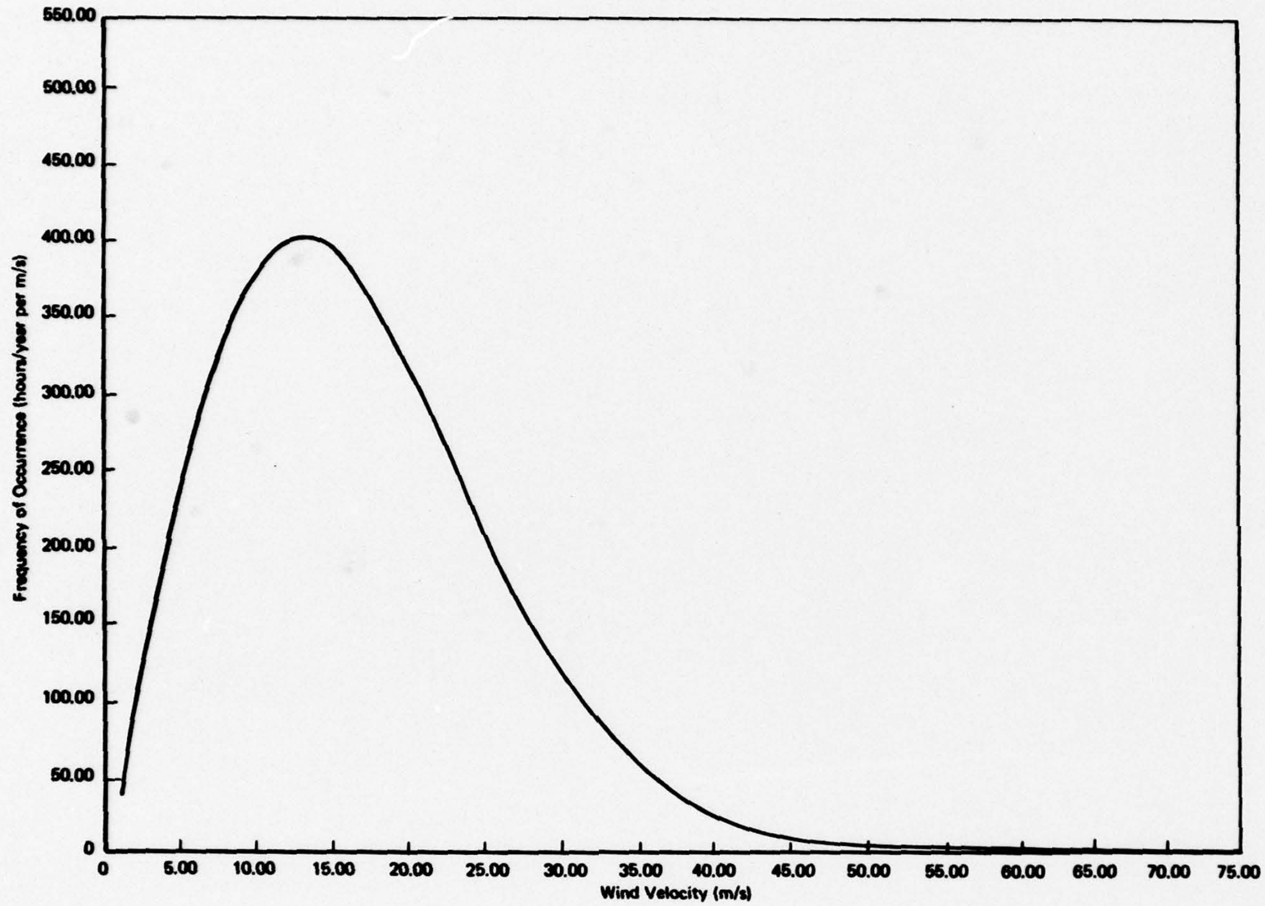
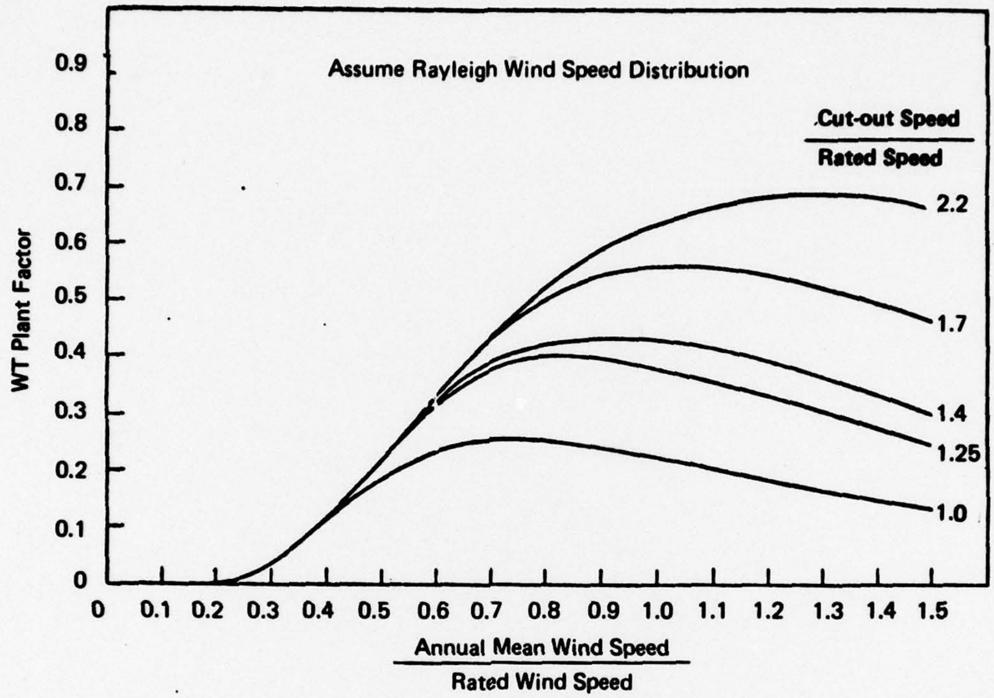


FIGURE 4–8 WEIBULL FREQUENCY DISTRIBUTION OF HOURLY AVERAGE WIND SPEED FROM MOUNT WASHINGTON SUMMIT OBSERVATORY (1976 Data)



Source: Cliff (1977).

FIGURE 4–9 WIND TURBINE GENERATOR PLANT FACTOR IN VARIOUS WIND REGIMES

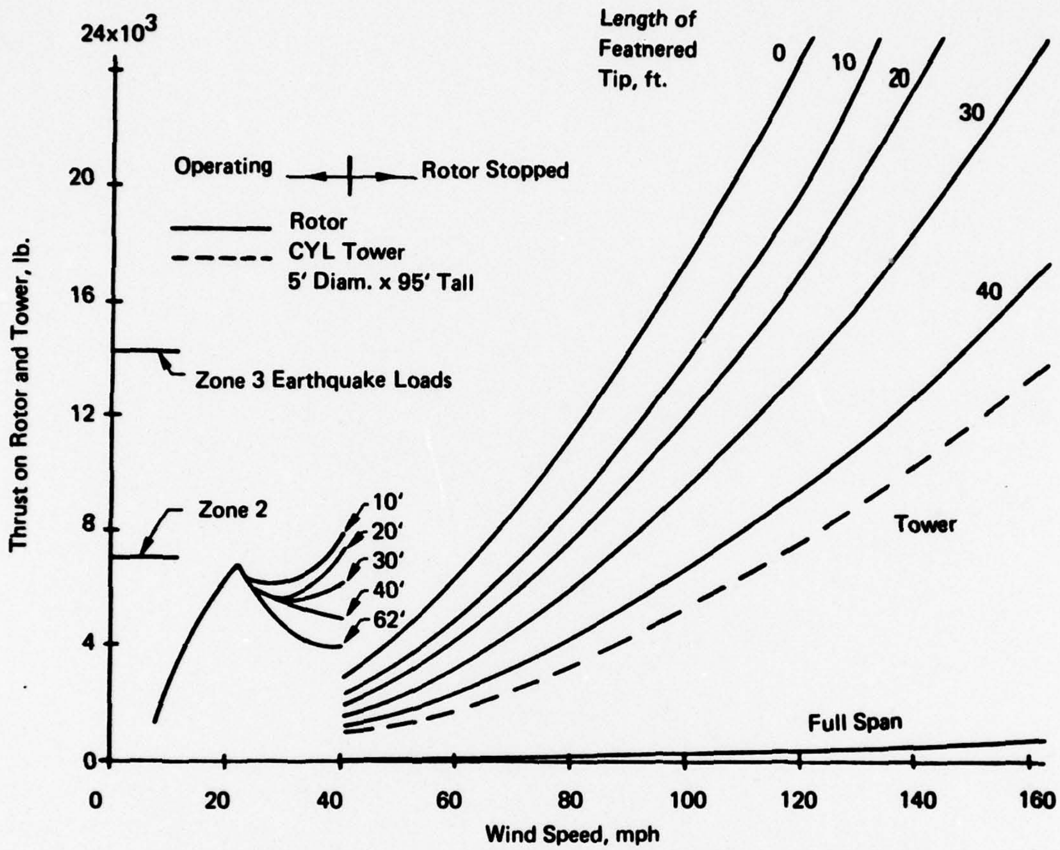
WTG Energy Systems, Inc. believes also that the variable pitch blade designs prevalent on DOE/NASA machine designs cannot respond rapidly enough to control the generator speed in elevated and gusty winds. However, they feel that a massive wind turbine rotor which is sufficiently strong to survive high winds will damp out the effects of gusts by its high rotational inertia.

It is also felt by many that if the WT cluster is closely tied (less than a mile) to a large, stiff grid, the inertia of the grid will dominate and damp out gust-indiced power oscillations. No sensor problems due to gusts have been encountered yet in the DOE Clayton, N.M. MOD-OA test program. Work continues at NASA Lewis Research Center, Power Technologies, Inc., and the University of Michigan to examine the stabilizing influence of dispersed clusters of WT's on the transients induced by gusts and weather fronts.

All of the above suggests that controlling a WT on mountain peaks may require more design work if the machine is to operate in high wind speeds and produce useful power. Due to a present lack of knowledge in the field, no increase in controls cost is assumed in calculating machine costs, and WT operation above present wind speed limits is not contemplated.

4.5.3.3 Effect of Increased Cut-Out Velocity on Tower Design

Figure 4-10, based on the MOD-X cylindrical tower design, allows a quick understanding of the effect of the cut-out velocity on the required tower strength. The force on the tower, generating both shear and moment loading, is the sum of the force on the rotor and on the tower. Allowing the cut-out velocity to increase raises the load on the tower at the cut-out velocity. However, as the tower must be designed to withstand the maximum loading, and this will typically occur at the maximum anticipated wind speed, raising the cut-out velocity, in itself, should not require strengthening the tower. Similarly, the strength of the blades is governed by the loading when the machine is shut down, exposed to the maximum wind speed. Although the blades, as well as the tower, need to be strengthened to withstand the increased maximum speed anticipated in the mountains, once this is done, both blades and tower could accommodate an increased cut-out speed (NASA, 1979).



Source: "200kW Wind Turbine Generator Conceptual Design Study," NASA (1979).

FIGURE 4–10 ROTOR AND TOWER THRUST FORCE VARIATION WITH WIND SPEED

4.5.4 Design Changes in Existing Machines for High Wind Speed Sites

4.5.4.1 Alternative Strategies

In Section 4.2.1 the discussion of controls indicated that the increase in annual energy output derived by raising the cut-out velocity above existing values of 20.1 m/s (45 mph) for DOE WT's was disappointing. When the cost is considered,this simple strategy appears to be poor. Both the tower and the blades must be strengthened to prevent machine failure at the highest maximum wind speed found in a high wind regime. To consider the appropriate design work required on machines intended to be used in the mountains, four design and-or control strategies have been considered for horizontal axis wind turbines (HAWT's). Future studies should look closely at vertical axis wind turbine (VAWT) design strategies as well. The HAWT alternative design strategies are the following:

Strategy One

- Leave the cut-in and rated velocities of existing machines unchanged.
- Strengthen the blades and tower.
- Plant factor will rise, as the average wind speed to rated wind speed ratio rises--see Figure 4-9.

Strategy Two

- Increase the rated wind speed of existing machines, holding V_M/V_R constant (V_M = site mean annual wind speed, V_R = Rated Wind Speed).
- Strengthen the blades and tower.
- Install a larger generator and transmission.
- Rated power will increase, but to first order, plant factor will not change because V_M/V_R = constant (assuming same wind speed distribution).

Strategy Three

- Increase the rated wind speed of existing machines, holding V_M/V_R constant.
- Shorten the blades.
- Strengthen the tower.
- Rated power will remain unchanged--the rotor area will shrink so as to just compensate for the increased rated wind speed.

Strategy Four

- Increase the rated wind speed, holding V_M/V_R constant.

- Shorten the blades.
- Strengthen the tower
- Install a larger generator and transmission.
- Rated power increases, as the rotor area is not reduced so much as to offset the effects of the increased rated wind speed.

4.5.4.2 Method of Analysis

To provide the lowest cost per kWh generated, a machine needs to be designed for a given annual average wind speed. The methodology used to assess the feasibility and define areas of needed design work for a high wind speed WT starts with the DOE/NASA MOD-X (200 kW conceptual design), the MOD-2 (2500 kW) WT, and the KAMAN (500 kW conceptual WT design) and defines the changes in component costs that will result from strengthening components or changing the rated output. In this way, the methodology makes maximum use of the information on existing designs and can consider many possible changes. The cost per kW finally calculated is, however, not as accurate as the cost calculated for existing designs, but the approach serves as an excellent tool for a sensitivity study.

The analysis assumes horizontal axis wind turbines are to be sited in high wind regimes. However, vertical axis wind turbines (VAWT) are potentially more suitable. Present generation VAWT's are rated at high wind speeds (13 M/S - 30 mph or greater) and are projected to have low costs per kW. ($320 per kW for ALCOA's 500 kW unit, Wind Energy Report, June 1979). High wind regimes may offer VAWT's an opportunity to achieve adequate plant factors and realize their potential to generate electricity inexpensively. However, VAWT technology is not as fully developed and the analysis technique used here would require more information and operating experience than presently exists.

In the analysis, the cost of a WT is composed of five elements: the blade and rotor, the drive train, the generator, the tower, and 'other' costs. The blade cost will change if the required strength or diameter changes. The cost of the drive train, primarily a speed-up transmission, depends on the rated power, as does the generator cost. The tower cost is a function of the maximum anticipated wind speed. 'Other' costs are defined to be all others and are assumed to be unchanged for a machine sited in a high wind regime. Defining C_u as the cost of the 'unmodified' machine, as presently designed:

$$C_u = B_u + D_u + G_u + T_u + O_u \qquad (4\text{-}4)$$

where: B_u, D_u, G_u, T_u, O are the blade, drive, generator, tower and and other costs of the unmodified machine.

Similarly, using an 'm' subscript for the modified machine, as strengthened for a high wind site:

$$C_m = B_m + D_m + G_m + T_m + O_m \qquad (4\text{-}5)$$

Define:

$$f_1 = B_u/C_u \qquad f_2 = D_u/C_u \qquad f_3 = G_u/C_u$$

$$f_4 = T_u \,/\, C_u \qquad f_5 = 1 - (\, f_1 + f_2 + f_3 + f_4 \,)$$

where f_i define the fractional costs for each machine element.

These data are available in published reports for the machines under study and are summarized in Table 4-5.

Then:

$$\frac{C_m}{C_u} = \frac{B_m}{B_u} \cdot f_1 + \frac{D_m}{D_u} \cdot f_2 + \frac{G_m}{G_u} \cdot f_3 + \frac{T_m}{T_u} \cdot f_4 + f_5 \qquad (4\text{-}6)$$

Using equation (4-6) allows the computation of the ratio of the modified machine cost to the unmodified cost, given the ratio of component costs and the f_i factors. The component cost ratios are derived below.

By calculating the component cost ratios for the three machines under the five strategies, in wind regimes with increasing average wind speeds, the capital cost of machines modified to survive in the mountains of New Hampshire can be computed. Dividing by the rated power yields the capital cost per kW. These values are graphed as a function of average wind speed and form the basis for the conclusions on appropriate designs.

4.5.4.3 Component Cost Ratios Between Modified and Unmodified Machines

Costs of Strengthening Blades

The blades are modeled as shell structures, carrying their load in the skin. This is appropriate for the fiberglass reinforced (composite) blades presently being considered. The cost is assumed to be directly proportional to the quantity of material used. Therefore,

$$\frac{B_m}{B_u} = \frac{\$/\text{lb.} \times \text{Density} \times \text{Volume of Blade}_m}{\$/\text{lb.} \times \text{Density} \times \text{Volume of Blade}_u} \qquad (4\text{-}7)$$

Conveniently, as cost per pound and density of the blade material cancel, to determine B_m/B_u only the volume of material ratio needs be found.

Table 4-5

FRACTIONAL COSTS OF WT COMPONENTS FOR MACHINES STUDIED

MACHINE	RATED POWER	RATED WIND SPEED (AT HUB HEIGHT)		RADIUS		MACHINE COST ELEMENT (PERCENT)				
				FEET	METERS	f_1 (BLADES)	f_2 (DRIVE)	f_3 (GENERATOR)	f_4 (TOWER)	f_5 (OTHER)
NASA - MOD-X (Concept)	200 kW	22.5	10.1	62.5	19.05	30.5	16.5	7.6	27.4	18.0
NASA - MOD-2	2500 kW	27.5	12.3	150	45.72	21.1	19.7	4.6	17.4	37.2
KAMAN 500 kW (Concept)	500 kW	27.3	12.2	75	22.85	24.4	17.3	9.7	21.6	27.0

Modeling the blade as a shell allows the computation of blade volume. It is found that the volume of the blade is proportional to ($W_r^2 \cdot R$), where: W_r is the blade width at the root and R is blade disc radius.

The constant cancels, and the ratio of the volume of the modified blade to the unmodified blade, and therefore the cost, is:

$$B_m/B_u = (W_{rm}^{\ 2} \cdot R_m)/(W_{ru}^{\ 2} \cdot R_u) \qquad (4\text{-}8)$$

where:

W_{rm}, W_{ru} are the blade widths at the root of the modified and unmodified blades.

R_m, R_u are the radii of the modified and unmodified blades.

The capacity of the blade to carry load is governed by the stress in the outermost fiber of the blade at the root. Assuming a non-buckling blade failure mode, the expression for the blade bending stress may be derived as:

$$S = K \cdot V^2R^2/W_r \qquad (4\text{-}9)$$

where:

K is a constant related to material properties and the blade shape and,

V is the wind velocity at which stress is to be calculated.

Requiring that the stress in the modified blade be no greater than in the unmodified blade specifies the blade design required to provide adequate strength:

$$\frac{S_m}{S_u} = \frac{V_m^{\ 2}}{V_u^{\ 2}} \cdot \frac{R^2_m}{R_u^{\ 2}} \quad \frac{W_{ru}}{W_{rm}} = 1 \qquad (4\text{-}10)$$

where S_m, S_u are the stress' in the modified and unmodified blade. S_m/S_u is 1 because the modified blade is to carry no more stress than the unmodified blade.

V_m is the average wind speed at the intended new site.

V_u is the average wind speed assumed by the designs of the MOD-X, MOD-2, or KAMAN WT.

Note: The maximum loading on the blades occurs at the maximum anticipated wind speed. As is discussed in Section 4.5.1, the maximum anticipated wind speed is very nearly a constant times the average wind speed. Therefore, V_m/V_u equals the ratio of the maximum wind speeds of a new site and the site assumed by NASA or KAMAN, as well as the ratio of the average wind speeds.

The blade cost increases as the square of the blade width at the root while the capacity to carry load increases only as the first power of the width for thin-walled structures. The reverse is true of the blade disc radius, suggesting that shortening the blades is the most cost effective way to survive higher wind speeds. However, this also reduces the rotor disc area and therefore raises the rated velocity for constant power rating or reduces the rated power for a constant rated wind velocity. The first and second strategies (see section 4.5.4.1) suggest strengthening the blade by enlarging the width at the root. In strategy three, holding the rated power constant, dictates the new (reduced) blade disc radius. In strategy four, the width at the root is held constant, and the disc radius must be reduced in order to maintain a constant stress. For all strategies, the stress in the modified and unmodified blades remains constant. Using equation 4-10, it is evident that this may be accomplished either by shortening the blades or thickening the width at the root. Then, using equation 4-8, relative blade costs may be estimated.

It is assumed in this analysis, and recommended in practice, that the entire blade by pitch controlled (vs. tip control). The conceptual design work on the MOD-X machine indicates that feathering the whole blade costs approximately the same amount as feathering only the tip. In addition, it is apparent upon inspection of Figure 4-10, that the unfeathered portion of a partial span pitch controlled blade is exposed to dramatically greater loads at maximum wind speeds. Not only does this require the blades to be stronger--the tower, too, would need to be additionally strengthened. To survive high winds, blades should be entirely feathered when the wind is above the cut-out speed.

Generator (G) and Drive Train (D) Cost Ratios

The cost of both the generator and the drive train are a function of the rated power. A least squares fit to a linear approximation, based on published costs (Reddoch (1978), Ligon (1976), General Electric Co. (1976), Kaman (1977), ADL interviews (1979)) for these components gives the following:

Transmission Cost ($) =

$78.11 · kW + $9672	100 < kW
$175.00 · kW + $2407	100 > kW

Generator Cost ($) =

$18.40 · kW + $2851	100 < kW
$25.56 · kW + $2637	100 > kW

It can be seen by the constant term that the economics of component size encourage larger machine sizes.

4.5.4.4 Tower Cost Ratios

Relying on design data from the MOD-X study (NASA, 1979), the bending moment at the base of a WT tower increases as the velocity to the 1.85 power. Modelling the tower as a thin-walled cylinder, carrying the load in the skin, the section modulus varies as the cube of the tower radius. Holding the tower height constant, and requiring that the stress in the outermost fiber at the base of the tower be unchanged and assuming a bending stress failure mode and not buckling, the ratio of the radius of a tower strengthened to withstand a wind velocity of V_m to that of a tower designed to withstand a wind velocity of V_u is:

$$\frac{R_m}{R_u} = \left(\frac{V_m}{V_u}\right)^{1.85/3}$$

As discussed previously, the ratio of the maximum wind speed at a site to that of the average wind speed is roughly equal to seven at most sites. However, existing designs are most frequently designed to withstand a 56 m/s (125 mph) maximum wind speed. The change in tower cost for higher maxima is based, therefore, on 56 m/s (125 mph) for V_u and seven times the average site velocity for V_m.

If the wall thickness is assumed to be a constant ratio of the tower radius in order to avoid buckling problems, the quantity of steel required varies as the square of the radius.

Therefore,

$$\text{STEEL}_{\text{Modified Design}}/\text{STEEL}_{\text{Unmodified Design}} =$$
$$(V_m/V_u)^{2 \cdot 1.85/3} =$$
$$(V_m/V_u)^{1.23}$$

Assuming the cost of the tower is a function only of weight,

$$\text{TOWER COST}_m/\text{TOWER COST}_u =$$
$$(V_m/V_u)^{1.23}$$

For towers examined, ranging from 6m to 60m (20 to 200 feet) in height, the assumption of this constant dollar per pound is good (see Ramler and Donovan, 1979), with a value ranging from \$.96 to \$1.13 per pound.

4.5.5 Evaluation of Alternative Strategies

All of the component cost ratios have now been defined in terms of average velocity and rated power. Equation 4-6 may now be applied to estimate the capital costs of machines, modified in different ways to function effectively in high wind regimes. The following three figures give the results of this analysis (Figure 4-11, 4-12, 4-13).

4.5.5.1 Strategy One (Use Existing WT Designs Unmodified)

Placing present WT designs in elevated wind regimes without raising their rated velocity is not cost effective. The plant factor rise, typically less than 20%, does not compensate for the dramatic increase in blade and tower cost associated with strengthening the WT for higher peak wind speeds. The mission analyses of General Electric (GE, 1976) and Kaman Aerospace Corporation (Kaman, 1977) both conclude that the optimum rated velocity is between 1.1 and 1.6 times the average velocity at the site. Because the rated wind speed for the NASA MOD-X is 10.1 m/s (22.5 mph) at hub height, and mountain sites have hub height average wind speeds of 11 to 14 m/s (25 to 31 mph), a machine with a rated wind speed comparable to that of the MOD-X installed in a high wind regime would be running suboptimally. From Figure 4-9, it is apparent that the plant factor does not increase enough in a high wind regime to compensate for the cost of strengthening the machine.

4.5.5.2 Strategy Two (Same Blade Diameter, Increased Rated Power)

With this strategy, the blade disc radius remains constant but both the blades and tower are strengthened to withstand the maximum loading they experience at the maximum wind speed. Hence, both the tower and blade costs rise. The ratio of the rated wind speed to the average wind speed remains constant. Therefore, the rated power and hence the transmission and generator size increase. Transmission and generator costs rise, but the rated power increases more rapidly--which would cause the cost per

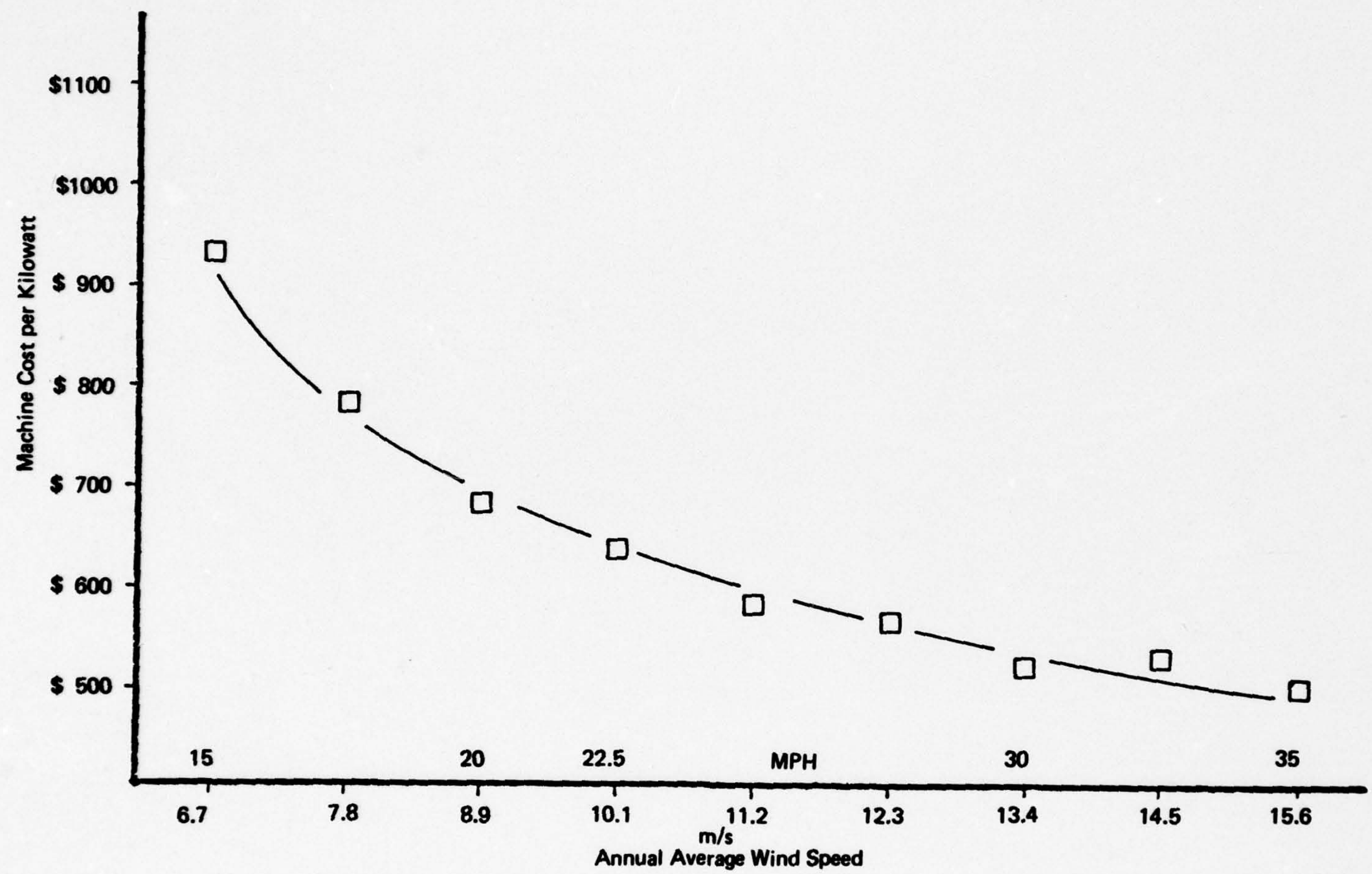


FIGURE 4–11 COST PER KW AS A FUNCTION OF ANNUAL AVERAGE WIND SPEED FOR MOD-2 WITH INCREASED RATED WIND SPEED AND REDUCED ROTOR DISC AREA (STRATEGY FOUR)

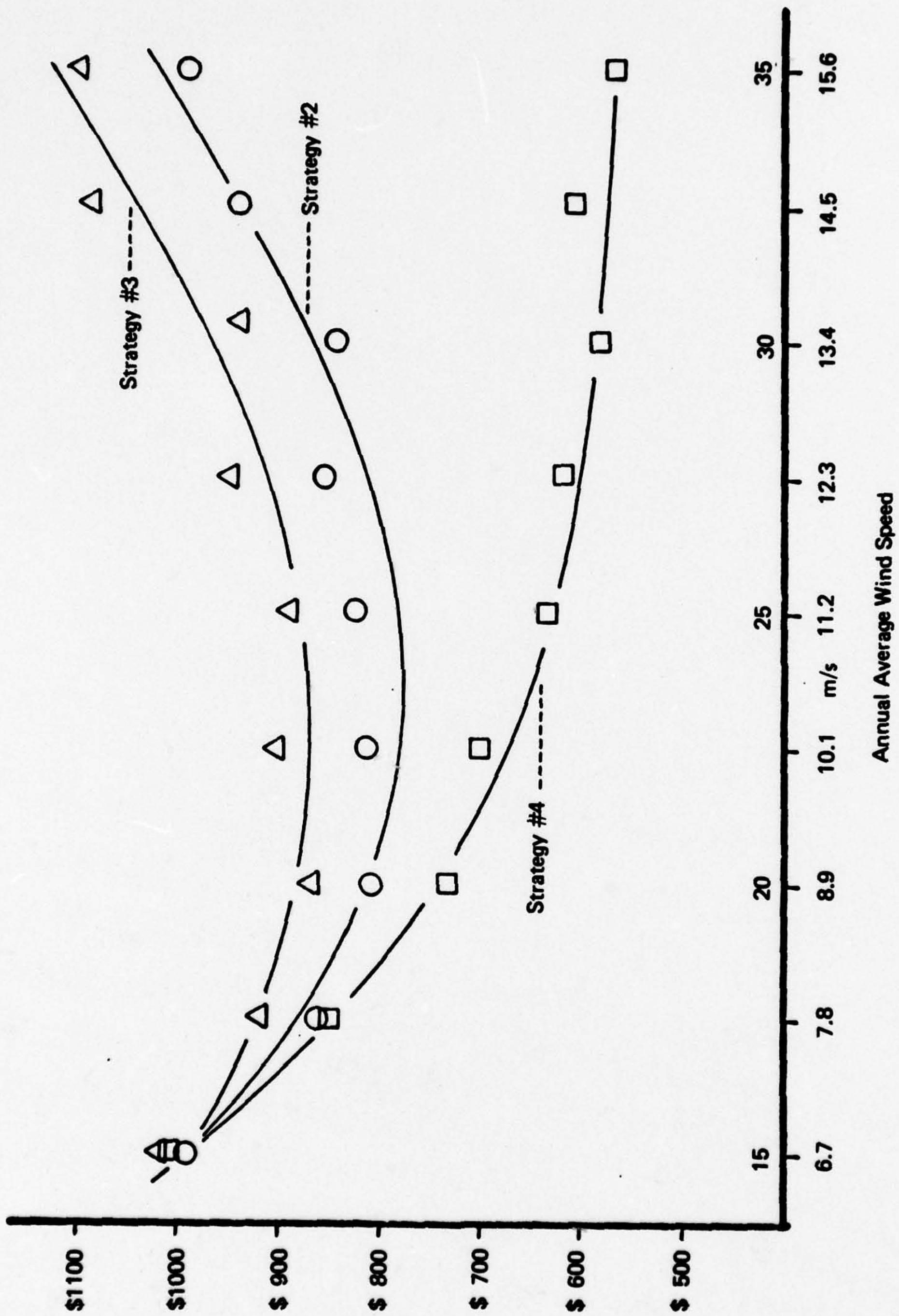


FIGURE 4–12 MODIFIED MOD-X
COST PER KW AS A FUNCTION OF ANNUAL AVERAGE WIND SPEED

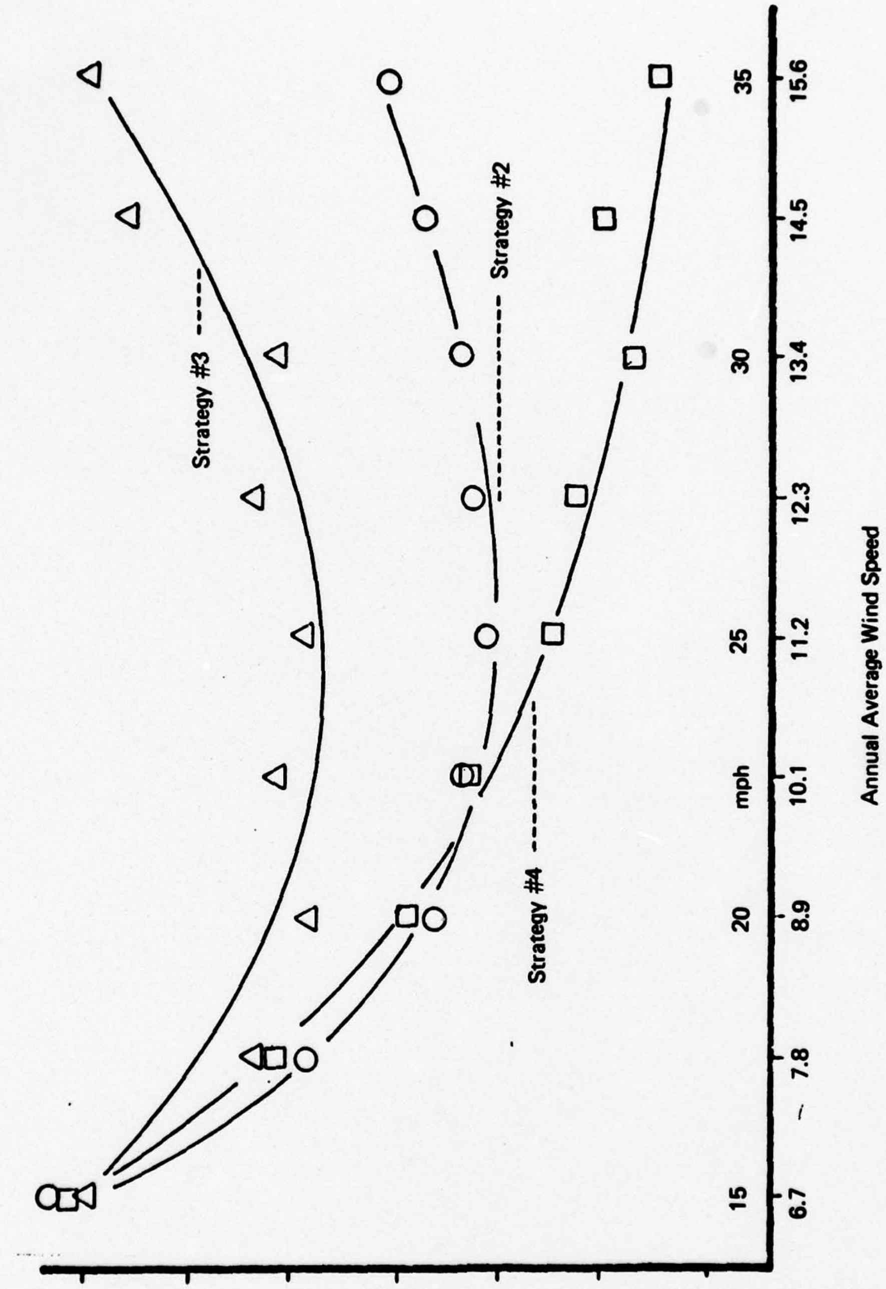


FIGURE 4–13 MODIFIED KAMAN 500 KW WT
COST PER KW AS A FUNCTION OF ANNUAL AVERAGE WIND SPEED

kW to continuously decline. However, the blade costs escalate more rapidly than does the rated power. The net effect on the MOD-X and KAMAN 500 kW machines is that following this strategy lowers the cost per kW only slightly with increasing average wind speeds and will eventually increase cost per kW at average wind speeds above approximately 12 m/s (27 mph) (see Figures 4-12 and 4-13).

4.5.5.3 Strategy Three (Reduced Blade Diameter, Rated Power Constant)

With this strategy, the WT installation benefits from the elevated average winds by using a smaller blade radius to support the same power rating as the original design concept. The transmission and generator are unchanged, the rated wind speed to average wind speed ratio remains constant, and the blade costs fall. This strategy is particularly appealing because it could be simply implemented--only new blades and a stronger tower would be required on existing designs. The results are apparent in Figure 4-12. The cost per kW declines, reaching a minimum at wind speeds between 8.9 and 11.2 m/s (20 - 25 mph). However, the minimum cost per kW under this strategy is not much less than the cost per kW in the wind regime assumed by NASA. The MOD-X, for example, has a cost per kW in a 6.3 m/s (14 mph) annual average wind speed of $1014 per kW. Using this strategy, a cost of about $875 per kW is the minimum expected value (see Figure 4-12). However, it remains an appealing strategy: design development work would be minimal and the installed cost declines $100 to $200 per kW.

4.5.5.4 Strategy Four (Reduced Blade Diameter, Increased Rated Power)

This strategy is a compromise between strategy two - constant blade diameter - and strategy three - constant rated power. The blades are allowed to become shorter, while retaining a constant width. The rated velocity to average velocity ratio also remains constant. The rated power rises, because the blades are not shortened so much as to reduce power. This approach to rendering existing machines suitable for use in high wind regimes generates the lowest estimates for the machine cost per kW. The design and capital costs are suggestive of the results which would be derived from a HAWT design exercise. In both Figures 4-12 and 4-13 the lowest curve is for strategy four. Using these curves shows that capital costs of $500 to $700 per kW appear plausible for WT's strengthened to survive mountain top wind regimes. To this cost must be added the interfacing costs discussed in Section 4.2.3, and displayed on Figure 4-3. Mountain top sites, if large enough to accept megawatt-scale installations and if located close to existing power lines, are potentially cost effective.

5.0 LEGAL AND INSTITUTIONAL BARRIERS TO WIND POWER DEVELOPMENT

5.1 Approach

The development of wind power in New Hampshire could be imagined to take place either as a result of a federally sponsored, large-scale, capital intensive project or through numerous small-scale private projects or a combination of the two. Although the basic driving force for any such development remains the same (i.e., rapidly increasing cost of fossil fuels), the specific stimulating factors and organizational aspects of the various possible scenarios could differ considerably.

Given the limited time frame for this study, a focused effort which minimized the effects of uncertainties in the development scenario was used to identify institutional barriers. The problem was approached by assuming that a person (e.g., individual, corporation, or government agency) had the resources and inclination to establish a wind turbine generator (WT) facility in the area of interest and that a logical progression would be followed for the project development. By hypothetically exploring the process, we have identified and investigated the major institutional constraints to such development.

5.2 Siting Considerations

5.2.1 Region of Interest

By intent of Congress and by contractual definition, this study of wind power has been focused on the Mt. Washington vicinity of New Hampshire (broadly interpreted as the White Mountains and other New Hampshire peaks). This area contains the principal topographic features of New Hampshire, including Mt. Washington itself, which (at elevation 6,288 feet) is the highest point in the eastern United States.

Prior to 1914, the entire area was in private ownership. However, the Weeks Law of 1911 established a boundary and authorized the purchase of private lands by the federal government to establish the White Mountain National Forest (WMNF). Federal land purchases have continued, the boundary has periodically been modified (expanded), and the WMNF now contains more than 730,000 acres, encompassing most of the significant mountain areas. A recent major purchase was the 6,500-acre Bretton Woods purchase in 1979.

Within the area of interest, there are several state parks located on small parcels of state-owned land. The rest of the land is in private ownership. A substantial portion of the privately held land at higher elevations is in the form of large parcels controlled by paper and timber companies.

5.2.2 Federal Land Use Constraints

5.2.2.1 Wilderness

The Wilderness Act of 1964 (16 USC 1131-1136) established a National Wilderness Preservation system ". . . to assure that an increasing population, accompanied by expanding settlement and growing mechanization, does not occupy and modify all areas within the United States and its possessions, leaving no lands designated for preservation and protection in their natural conditions."

The term "wilderness" has a range of meanings in common usage but is defined in the Act as follows: "A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." An area of wilderness is further defined to mean ". . . an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements of human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value."

The Wilderness System is composed of federally owned areas designated by Congress as "wilderness areas" and administered by the agency within whose land the wilderness resides. The Act established a mechanism for review of roadless areas, public notification, presidential recommendation, and Congressional designation of such areas. It also declared the purposes of the Act to be supplemental to the purposes for which national forests are established and administered and mandated that ". . . wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use."

The Act states that "Except as specifically provided for in this chapter, and subject to existing private rights, there shall be no commercial enterprise and no permanent road within any wilderness area designated by this chapter and, except as necessary to meet minimum requirements for the administration of the area for the purpose of this chapter (including measures required in emergencies involving the health and safety of persons within the area), there shall be no temporary road, no use of motor vehicles, motorized equipment or motorboats, no landing of aircraft, no other form of mechanical transport, and no structure or installation within any such area."

Notwithstanding the apparently exclusionary nature of the purposes of wilderness and the prohibited activities under the Act, provision is made for prospecting within wilderness areas as follows: "Nothing in this chapter shall prevent within national forest wilderness areas any activity, including prospecting, for the purpose of gathering information about mineral or other resources, if such activity is carried on in a manner compatible with the preservation of the wilderness environment."

Although provision is made for recovery of oil, gas, and mineral resources prior to December 31, 1983, the Act gives no consideration to wind as a potentially recoverable resource. Consequently, it would appear that wind prospecting could take place within wilderness areas (as long as structures and motorized equipment were not used) but without specific action of the President, erection of any wind turbine or transmission lines would be strictly forbidden under the present law. The Act states that ". . . the President may, within a specific area and in accordance with such regulations as he may deem desirable, authorize prospecting for water resources, the establishment and maintenance of reservoirs, water-conservation works, power projects, transmission lines, and other facilities needed in the public interest, including the road construction and maintenance essential to development and use thereof, upon his determination that such use or uses in the specific area will better serve the interests of the United States and the people thereof than will its denial." Thus, it would appear that the President could make a determination that WT development in a Wilderness Area should be permitted. It is likely that such a determination would only be made after thorough public consideration of the issue through the planning process discussed below in Section 5.2.2.3.

5.2.2.2 Appropriate Use of National Forest

National forests are forest bearing public lands which have been set apart and reserved by the President of the United States and are administered by the U.S. Forest Service, an agency of the U.S. Department of Agriculture. The President's authority to establish national forests is codified in 16 USC 471. All public lands set aside and reserved as national forests under Section 471 ". . . shall be as far as practicable controlled and administered in accordance with the following provisions. No national forest shall be established except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States; but it is not the purpose or intent of these provisions, or of said section, to authorize the inclusion therein of lands more valuable for the mineral therein, or for agricultural purposes, than for forest purposes." (16 USC 475) It is interesting to note that in June 1897 when this portion of the law was passed, there was no consideration of wind energy as a valuable resource which might someday compete for the same land as could be used for forests.

The Multiple Use-sustained Yield Act of 1960 further defined policy regarding the appropriate use of national forests in stating that "It is the policy of the Congress that the national forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes." (16 USC 528) The same section restates Congressional intent to treat mineral resources in national forests as a special case. In Section 529 "the Secretary of Agriculture is authorized and directed to develop and administer the renewable surface resources of the national forests for multiple use and sustained yield of the several products and services obtained therefrom. In the administration of the national forest, due consideration shall be given to the relative values of the various resources in particular areas." While wind resources are not specifically recognized or mentioned, the establishment and maintenance of wilderness areas is.

The definition of "Multiple Use" includes harmonious and coordinated management of all the various renewable resources taking into account their relation with each other, and recognizing that some parts of the ". . . land will be used for less than all the resources." Management must take place ". . . without impairment of the productivity of the land, with consideration being given to the relative values of the various resources, and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output." (16 USC 531) "Sustained yield" implies a high level of output of renewable resources of the forest without impairment of the productivity of the land.

In contrast with the purposes of and management practices applied to national forests, the purposes associated with national parks are more restrictive (i.e., ". . . conserving their scenery, wildlife, natural and historic objects and providing for their enjoyment in a manner that will leave them unimpaired for the enjoyment of future generations. . . ." In addition, support facilities and services within national parks are to be ". . . consistent to the highest practicable degree with the preservation and conservation of the areas." (16 USC 20)

5.2.2.3 Federal Planning Process

5.2.2.3.1 Resources Planning Act

The Forest and Rangeland Renewable Resources Planning Act of 1974 (FRRRPA) and subsequent legislation relating to management of the national forests has been codified in 16 USC 1600-1676. In FRRRPA, Congress found (among other things) that:

"(1) the management of the Nation's renewable resources is highly complex and the uses, demand for, and supply of the various resources are subject to change over time;

(2) the public interest is served by the Forest Service, Department of Agriculture, in cooperation with other agencies, assessing the Nation's renewable resources, and developing and preparing a national renewable resource program, which is periodically reviewed and updated;

(3) to serve the national interest, the renewable resource program must be based on a comprehensive assessment of present and anticipated uses, demand for, and supply of renewable resources from the Nation's public and private forests and rangelands, through analysis of environmental and economic impacts, coordination of multiple use and sustained yield opportunities as provided in the Multiple-Use Sustained-Yield Act of 1960 and public participation in the development of the program." (16 USC 1600)

In response to these findings, Congress set forth requirements for a detailed planning process which includes development by the Secretary of Agriculture of a Renewable Resource Assessment, a Renewable Resource Program, and Land and Resource Management Plans for each unit (each specific national forest) of the national forest system. Specific features of the planning process are designed to assure that public inputs are sought out, evaluated, and appropriately incorporated as the planning develops, and is periodically updated.

<u>Renewable Resourse Assessment</u>

The assessment is to include:

"(1) an analysis of present and anticipated uses, demand for, and supply of the renewable resources, with consideration of the international resources situation, and an emphasis of pertinent supply and demand and price relationship trends;

"(2) an inventory, based on information developed by the Forest Service and other Federal agencies, of present and potential renewable resources, and an evaluation of opportunities for improving their yield of tangible and intangible goods and services, together with estimates of investment costs and direct and indirect returns to the Federal Government;

"(3) a description of Forest Service programs and responsibilities in research, cooperative programs and management of the National Forest System, their interrelationships, and the relationship of these programs and responsibilities to public and private activities; and

"(4) a discussion of important policy considerations, laws, regulations, and other factors expected to influence and

affect significantly the use, ownership, and management of forest, range, and other associated lands." (16 USC 1601)

The Assessment is to be updated on a ten-year cycle at the end of each decade. In addition, ". . . as part of the Assessment, the Secretary of Agriculture shall develop and maintain on a continuing basis a comprehensive and appropriately detailed inventory of all National Forest System lands and renewable resources. This shall be kept current so as to reflect changes in conditions and identify new and emerging resources and values." (16 USC 1603)

It would seem appropriate with the end of a decade approaching to include potential wind power resources in the inventory under the category of new and emerging resources and values, although to date, there has apparently been no attempt to do so in the White Mountain National Forest.

Renewable Resources Program

The program is to be prepared and updated on a five-year cycle and is to cover a forty-year planning period. It is to be developed in accordance with multiple-use, sustained-yield concepts, and is to provide for ". . . protection, management, and development of the National Forest System, including forest development roads and trails; for cooperative Forest Service Programs and for research." The program is to include:

- an inventory of investment needs and opportunities;
- identification of program outputs, costs and benefits;
- a discussion of program priorities;
- a personnel study for program implementation and monitoring;
- program recommendations which (among other things) ". . . recognize the fundamental need to protect and, where appropriate, improve the quality of soil, water, and air resources; and state national goals that recognize the interrelationships between and interdependence within the renewable resources." (16 USC 1602)

Land and Resource Management Plans

Under Section 1604, the Secretary of Agriculture is required (by September 30, 1985) to ". . . develop, maintain and, as appropriate, revise land and resources management plans for units of the National Forest System, coordinated with the land and resource management planning process of State and local governments and other Federal agencies." Furthermore, "The Secretary shall provide for public participation in the development, review, and revision of land management plans including, but not limited to, making the plans or revisions available to the public at convenient locations in the vicinity of the affected unit for a period of at least three months before final adoption, during which period the Secretary shall publicize and hold public meetings or comparable pro-

cesses at locations that foster public participation in the review of such plans or revisions."

The unit plans are to be developed, maintained, and revised in accordance with multiple-use, sustained-yield principles as defined by the 1960 Act ". . . and, in particular, include coordination of outdoor recreation, range, timber, watershed, wildlife and fish, and wilderness."

The Act specifies that the plans shall:

"(1) form one integrated plan for each unit of the National Forest System, incorporating in one document or one set of documents available to the public at convenient locations, all of the features required by this section;

"(2) be embodied in appropriate written material, including maps and other descriptive documents, reflecting proposed and possible actions, including the planned timber sale program and the proportion of probable methods of timber harvest within the unit necessary to fulfill the plan;

"(3) be prepared by an interdisciplinary team. Each team shall prepare its plan based on inventories of the applicable resources of the forest."

Plan amendments and revisions are allowed and must be accomplished following multiple-use, sustained-yield principles. If proposed changes are significant, there must be public involvement comparable to that required to initially complete the plan as described above. Unit plans must be revised at least every 15 years but also should be revised on a shorter time frame if the Secretary finds that conditions in a unit have changed significantly.

Prior to the passage of FRRRPA, the Forest Service had established a three-phase planning process whereby an Area Guide, a Forest Plan, and Unit Plans (within the forest) were generated in sequence. At each phase in the development of plans, the new documents are based upon policy laid down in the previous work, and they contain more details than prior documents. In the case of the White Mountain National Forest, Steps I and II were completed by August 1974. As of June 15, 1979, unit plans for five of the 11 planning units within the forest had been completed.

The planning process already used in the White Mountains appears to exceed the requirements specified in FRRRPA in some respects. Specifically, the use of planning units within the national forest is on level of detail beyond that required by FRRRPA. Currently (August 1979), effort is being expended to make results of the past planning process conform with FRRRPA. A new FRRRPA "Unit Plan" corresponding to a revised and more detailed version of the 1974 "Forest Plan" will be developed by 1983. The new forest-wide FRRRPA unit plan will incor-

porate information at a level of detail comparable to that developed for the earlier sub-forest unit plans. In the meantime, the lands will be managed according to existing plans, and detailed data collection is underway to provide information necessary for inclusion in the new plan.

The 1974 Forest Plan and the subsequent unit plans classified all land within the White Mountains National Forest by Management Area category or according to special use category.

The management objective for "Special Areas" is as to ". . . insure protection of areas of particularly significant geological, historical, scientific, or vegetative interest. Manage areas currently being considered for special classification or those with known potential for consideration within the requirements of such considerations." Furthermore, ". . . areas identified in pending legislation, such as proposed Eastern Wilderness Areas, will be withdrawn from road construction, timber harvesting, recreation construction, or other uses that could reduce the value for which the areas are being considered until the legislative processes are concluded."

"The existing special areas [in the White Mountains] are as follows:

"(1) The Great Gulf Wilderness, 5,552 acres, will be managed according to the Wilderness Act of 1964 with emphasis on preserving the basic wilderness resource and providing a wilderness experience.

"(2) Appalachian Trail, 119.2 miles total inside National Forest boundary, of which 9.2 miles is on private land and needs acquisition in fee or easement. The trail zone is 400 feet wide and occupies 2,750 acres of National Forest land. The Appalachian Trail will be managed according to guidelines established under the National Scenic Trails System Act in a separate plan. Management of the Appalachian Trail will be closely coordinated with the Green Mountain National Forest.

"(3) The Bowl Research Natural Area, 510 acres, to be preserved in its natural state for study of natural process unaffected by man. Recreationists should <u>not</u> be encouraged to enter this area.

"(4) Scenic Areas:

(a)	Gibbs Brook	900 acres
(b)	Greeley Ponds	810 acres
(c)	Lafayette Brook	900 acres
(d)	Lincoln Woods	18,560 acres
(e)	Nancy Brook	460 acres

(f)	Pinkham Notch	5,600 acres
(g)	Rocky Gorge	70 acres
(h)	Snyder Brook	36 acres
(i)	Sawyer Ponds	1,130 acres

"(5) Hubbard Brook Experimental Forest, Massabesic Experimental Forest, and Bartlett Experimental Forest will be managed in response to needs and programs of the Northeast Forest Experiment Station." (Forest Plan, 1974*)

There are four Management Area Categories ranging from I to IV, with Management Area IV land use emphasizing aesthetics and preservation, and a broader spectrum of allowed uses for Management Areas I through III. Figure 5-1 depicts graphically the relative emphasis on various resource use-activity by Management Area. The principal objectives of each management area and policies which are particularly constraining for potential wind power development are shown in Table 5-1.

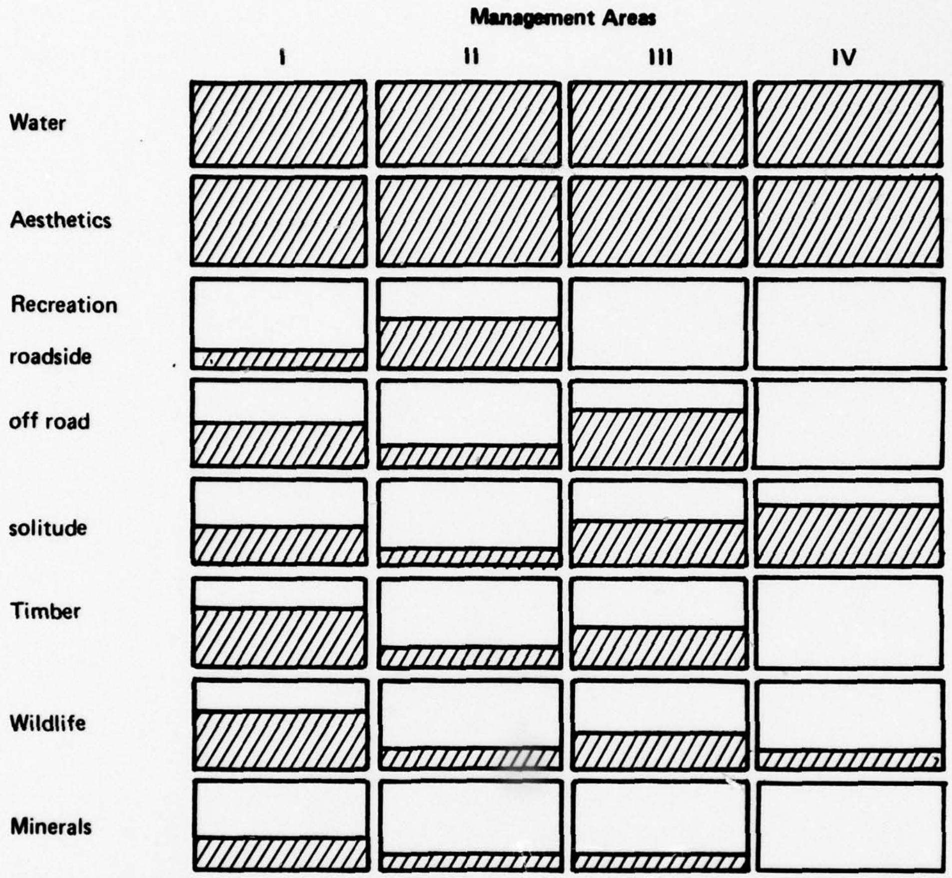
The Area Plan (Guide for Managing the National Forests in New England, 1973) presented the expected percentage land allocation to management areas within the White Mountain National Forest as follows:

Management Area	Expected Allocation (%)	Level of Restriction
I	53 ± 3	Somewhat Restricted
II	8 ± 2	
III	23 ± 3	
IV	16 ± 2	Severely Restricted

Relative to national forests in less densely populated areas of the country, this allocation scheme is heavily weighted to the low intensity uses fostered by Category III and IV management areas to emphasize natural preservation. There are at least two main reasons for this emphasis:

1) "A large variety of birds, mammals, amphibians, reptiles, and other species of wildlife use the National Forest at some period during their life cycles. Special habitat protection is needed for several species of fish and wildlife on the Forest. The headwaters of four major river systems (Connecticut, Merrimack, Saco, and Androscoggin), which are vital to the Atlantic Salmon restoration project, exist within the Forest boundary. Seven species of wildlife on the Forest

*Forest Plan White Mountain National Forest. Eastern Region, Forest Service, U.S. Department of Agriculture, August 1974.



Note: Hatched area represents relative emphasis.

Source: *Guide for Managing the National Forests in New England.*

FIGURE 5–1 COMPARISON OF RESOURCE USE-ACTIVITY BY MANAGEMENT AREAS

TABLE 5-1

COMPARISON OF MANAGEMENT AREA OBJECTIVES
AND SPECIAL LAND USE POLICIES

Management Area	Principal Objective	Special Land Use Policy
I	Maintain a healthy, productive forest cover to provide high quality timber products and optimum wildlife habitat conditions. Provide opportunities for varied dispersed recreation experiences in association with other uses. (Recreation Experience Level 2)	
II	To provide a mixture of resource uses and outputs which will emphasize opportunities for concentrated or high density, recreational experiences. (Recreational Experience Level 3)	Utility corridors must be out of sight except where necessary to serve a National Forest facility.
III	To provide a mixture of resource uses and outputs which will emphasize dispersed recreation opportunities offering a near natural visitor experience. Provide timber products consistent with emphasized aesthetic values. (Recreation Experience Level 2)	No utility corridors or antennas will be permitted in this area.
IV	To provide a mixture of resource uses and outputs which will emphasize opportunities for a natural recreational experience with a high degree of solitude. (Recreation Experience Level 1)	No utility corridors or antennas will be permitted in this area.

Source: Forest Plan, White Mountain National Forest, 1974.
Note: See overlays #1 and #2 to Figures A-1 and A-2 (Appendix A) for maps of restricted regions within the WMNF.

(Osprey, Fisher, Marten, Canada Lynx, Great Blue Heron, Spruce Grouse, and Northern Three-toed Woodpecker) are classified as 'unique' while the Peregrine Falcon is considered 'endangered.' The protection and management of special habitats, such as deer yards, wetlands, and natural openings, are critical to the life cycles of many indigenous species." (Forest Plan, 1974)

2) "Comparable recreation experiences close to concentrated eastern population centers are limited. The growth in recreation demands are likely to create a variety of conflicts with other resource uses. In some parts of the forest, recreation activities have already strained the carrying capacity of the resource itself. The value of the forest to serve New England, and the Nation, from a recreational standpoint will continue to grow in importance in the future.

"The White Mountain National Forest is being managed under the multiple use concept with emphasis upon mountain-oriented forms of recreation. At the present time, recreation has the highest relative value and is basic to the management programs for the forest." (Forest Plan, 1974)

At the present time, areas III and IV (see overlay #1 to Figures A-1 and A-2) do not permit the installation of WT's. The prospects for a change in the present emphasis will have to be weighed against the purpose of establishing national forests and balanced through multiple-use, sustained-yield considerations. It seems likely that a significant amount of public participation and possibly Congressional or Presidential action would be required to make a substantial change. Depending on the urgency with which a change is addressed, it would seem that pressure would have to build and the process of change be carried out over a period greater than one year and possibly as long as 10 to 15 years. Whereas the previous legislation and planning did not thoroughly consider energy issues, it is anticipated that the new plan (which is expected to be complete sometime between 1983 and 1985) will address the energy issue.

5.2.2.3.2 RARE II

The Wilderness Act of 1964 established a situation which led to the Roadless Area Review and Evaluation (RARE II).

"RARE II is a comprehensive process, instituted in June 1977, to identify roadless and undeveloped land areas in the National Forest System and to determine their general uses for both wilderness and other resource management and development. The RARE II process identified 2,919 roadless areas encompassing 62 million acres in National Forests and National Grasslands in 38 States and Puerto Rico. The process led to recommendations or allocations of each of these areas to wilderness, for multiple uses other than wilderness (here-

inafter referred to as nonwilderness), or as needing further planning for all uses including wilderness. The nonwilderness category includes different mixes of multiple uses other than wilderness, including but not limited to those permitting campground and other recreation site development, timber harvest, intensive range management, and road construction on the one hand, and relatively primitive wildlife habitat, watershed, and vegetation manipulation on the other. The specific multiple use direction is established and periodically updated in land and resource management plans.

"Extensive as this project of public land allocation has been, it is still part of the broad planning direction for all Forest Service activities laid out by Congress in the Forest and Rangeland Renewable Resources Planning Act [FRRRPA] of 1974 and the National Forest Management Act of 1976.

"The primary goal of RARE II has been to select appropriate roadless areas to help round out the National Forest System's share of a quality National Wilderness Preservation System and, at the same time, maintain opportunities to get the fullest possible environmentally sound use from other multiple use resources and values. The RARE II process has carefully evaluated physical, biological, social, and economic impacts and tradeoffs involved in development of the proposed action.

"The RARE II proposed action for allocation of National Forest System land to wilderness takes into consideration its relationship to the entire National Wilderness Preservation System. The Wilderness System, containing lands administered by the Forest Service, National Park Service, Bureau of Land Management and Fish and Wildlife Service, now totals 19 million acres of Congressionally-designated wilderness. A total 15.2 million acres of this total is in 110 units within the National Forest System. In addition, the Administration has endorsed proposals for an additional 22.9 million acres of wilderness from lands administered by the three agencies, including 3.3 million acres in the National Forest System." (RARE II, 1979)

In the White Mountains, there are presently two designated wilderness Areas accounting for nearly 26,000 acres (areas NF033 and NF064, overlay #2 to Figure A-2). RARE II recommended four additional areas containing over 169,000 acres for Wilderness designation (Wilderness Recommendation Areas Numbered 9064, 9066, 9067 and 9072 in overlay #2 to Figure A-2 in Appendix A), and six areas containing 73,000 acres for Further Planning (Further Planning Areas Numbered 9068, 9069, 9073, 9074, 9075, 9076 in overlay #3 to Figure A-2). At this writing (August 1979), Congress is still debating whether to accept the RARE II recommendations. The effect is to hold those areas recommended for Wilderness and Further Planning in a state of limbo. Most of these lands are in Management Areas III or IV in the White Mountains and will be subject to land use constraints which would

discourage intensive development (including that of wind turbines). Estimates on timing of Congressional action on RARE II range from action during this session to no action for four or more years.

5.2.2.4 Summary of Federal Land Use Constraints

The planning process which determines the allowable land uses in national forests is based on authority delegated to the Forest Service by Congress over many years. It also incorporates a significant amount of input from the general public. Thus, there is substantial weight in the management plans which have been (and/or are being) prepared for the White Mountain National Forest. The figures in Appendix A depict the geographic distribution of areas where significant land use constraints are in effect. It can be noted that substantially all the land at elevations higher than 2,500 feet lie in restricted areas--either in Management Areas III or IV; or designated Wilderness; or Special Areas (e.g., Scenic Areas); or in RARE II areas recommended for Wilderness or Further Planning.

Substantial barriers would have to be overcome to alter the existing management plans sufficiently to allow large-scale wind power development within the White Mountain National Forest. However, it should be noted that the issue of wind power generation in national forests has simply never been considered formally in the existing laws, regulations, and management plans. Thus, it could be argued that the issue was merely overlooked, and that development of wind generated electric power on national forest land constitutes a legitimate land use within the multiple-use, sustained yield context.

5.2.3 State and Local Land Use Constraints

5.2.3.1 State Regulations Relating to Energy Facility Siting

New Hampshire has no statewide zoning authority, but exercises control over siting of certain classes of energy facilities through Chapter 162-F and Chapter 162-H of the New Hampshire Revised Statues--Annotated (RSA 162-F and RSA 162-H).

Chapter 162-F establishes a procedure for planning, siting, and construction of bulk power supply facilities. As defined in the statute, "bulk power supply facilities" means:

"(a) Electric generating station equipment and associated facilities designed for or capable of operation at a capacity of 50 megawatts or more;

"(b) An electric transmission line of design rating of 100 kilovolts or more, associated with a generating facility outlined in (a), over a route not already occupied by a transmission line or lines;

"(c) An electric transmission line of a design rating in excess of 100 kilovolts that is in excess of 10 miles in length over a route not already occupied by a transmission line or electric transmission lines of a design rating in excess of 100 kilovolts which the site evaluation committee or commission determines should require a certificate because of a substantial environmental impact." (RSA 162-F:2)

The law also establishes a "site evaluation committee" defined as follows:

"The bulk power supply facility site evaluation committee shall consist of the executive director and the chief aquatic biologist of the water supply and pollution control commission, the commissioner of the department of resources and economic development, the director of fish and game, the director of the office of planning, the chairman of the water resources board, the director of the radiation control agency, the executive secretary of the air pollution control commission, the commissioner of the department of health and welfare, the director of the division of parks, the director of the division of resources, the chairman of the public utilities commission and the chief engineer of the public utilities commission. The director of water supply and pollution control commission shall be chairman of the committee. Provided that in the event there is created an agency or department whose function is the protection and preservation of the environment of the state, then the director of that agency shall be the chairman of the committee." (RSA 162-F:3)

The law specifies that no bulk power supply facilities may be built within the state without a certificate of site and facility. The utility companies must plan for the siting of bulk power supply facilities 10 to 15 years in advance and must apply for a certificate of site and facility two years in advance of the planned date of commencement of construction. Public hearings and appropriate studies must be conducted by the siting committee and the Public Utilities Commission.

"The site evaluation committee, after having considered available alternatives and the environmental impact of the site or route, must find that the site and facility will not unduly interfere with the orderly development of the region with due consideration having been given to the views of municipal and regional planning commissions and municipal legislative bodies and will not have an unreasonable adverse effect on esthetics, historic sites, air and water quality, the natural environment, and the public health and safety, and shall send its findings to the commission within 14 months of the filing of an application for a certificate of site and facility. The commission shall issue or deny a certificate and shall

be bound by the findings of the site evaluation committee. In its decision, the commission must find that the construction of the facility:

"(a) Will not unduly interfere with the orderly development of the region with due consideration having been given to the views of municipal and regional planning commissions and municipal legislative bodies;

"(b) Is required to meet the present and future demand for electric power;

"(c) Will not adversely affect system stability and reliability and economic factors; and

"(d) Will not have an unreasonable adverse effect on esthetics, historic sites, air and water quality, the natural environment, and the public health and safety." (RSA 162-F:8)

To attain the threshold capacity of 50 megawatts for regulation under this chapter, a rather major wind turbine cluster installation (wind farm) would have to be contemplated. Such a major commitment to wind energy is probably quite premature, so RSA 162-F is not expected to apply to wind power development in New Hampshire in the near future.

Chapter 162-H regulates the siting, construction and operations of "energy facilities." An energy facility is defined as "any industrial structure other than bulk power supply facilities that may be used substantially to extract, manufacture, or refine sources of energy." A source of energy includes power derived from a national resource. Since the legislation originated in response to a need for regulation of offshore petroleum facilities, there has been some discussion as to the extent of jurisdiction. It has been suggested that low-head hydroelectric facilities are not subject to this chapter, and as a matter of policy the Energy Facility Evaluation Committee does not consider such facilities. (Energy Law Institute, 1978)

Whether WT's would be regulated under this chapter is presently a matter of interpretation. In any event, the regulatory procedures under RSA 162-H parallel those specified in RSA 162-F. The energy facility evaluation committee consists of the members of the bulk power supply facility site evaluation committee, and a permit is issued to the successful applicant in lieu of a certificate of site and facility.

If the total electrical output of a facility is less than 5 megawatts, it is not classified as a utility, and no state siting regulations apply. Special advantages accrue to such power generators, and are discussed in Chapter 6.

In practice, the Public Utilities Commission reviews all major permit applications and holds hearings where concerned state agencies and private citizens review the merits of applications.

5.2.3.2 Local Zoning

Several assessments of legal and institutional barriers to wind turbine generator installations have addressed zoning and building code restrictions. (Taubenfeld and Taubenfeld, 1976; George Washington University, 1979) In practice, building codes have not been found to present significant barriers. (Coit, 1979) New Hampshire is not a home-rule state, and to date local zoning in the cities and towns has not been developed to a high degree. In the area of main interest (i.e., the White Mountains), zoning constraints are not anticipated to be a problem.

5.2.4 Right of Way Availability and/or Procurement

5.2.4.1 Federal Lands Special Use Permit

No WT's or transmission lines could be constructed on national forest land without first obtaining a Special Use Permit. Forest Service regulations spell out the procedures for filing and processing special use applications. Public hearings must be held, and the decision to grant or deny the special use permit must be made within the context of the forest management plans. At present, it is quite unlikely that high elevation sites in the White Mountain National Forest would be approved as WT sites or that power line rights of way would be granted from such high elevation locations. It is unwritten Forest Service policy to encourage wind power development in regions outside the boundary of the national forest and to adhere to strict interpretation of the present restrictive forest management plans within the boundary.

5.2.4.2 Non-Federal Lands

Informal conversations with observers of wind power development activities in New Hampshire have indicated that some significant sentiment exists in favor of using state lands (including state parks) as WT sites. This study did not find binding restrictions which would preclude such use of state lands. Presumably, a review of such a proposal could be conducted under the RSA 162-H procedures.

With regard to the use of private lands, there are no restrictions which cover facilities with generating capacities under 5 megawatts. Generating facilities with greater than 5 megawatt capacity are "utilities" and are regulated by the Public Utilities Commission and RSA 162-F or RSA 162-H. Once the PUC has issued a certificate of site and facility, the utility may obtain a power line right of way easement either through negotiation with a willing seller or through condemnation proceedings.

5.3 Environmental Review

5.3.1 Federal Review

In the decade since the National Environmental Policy Act of 1969 (NEPA) became effective, a substantial change has occurred in the routine level of environmental consideration which is given to major projects of all kinds. During the development to its present state, the NEPA process has upon occasion been used as a powerful tool to delay, alter, and in some cases indefinitely defer proposed projects with substantial adverse environmental impacts. As the NEPA process developed over the years, environmental considerations have become better integrated with traditional engineering and economic factors at early stages in the project design. Thus, some of the main purposes of NEPA have been realized.

The portion of NEPA which has accounted for the delays, etc., is Section 102-2(c) which requires that an Environmental Impact Statement (EIS) be prepared for federal actions significantly affecting the environment. In the early 1970's the ramifications of this requirement were not well understood, yet and some EIS's were literally a stack of documents more than 10 feet high. As experience was gained with the process, the courts clarified the requirements, and with the publication of new guidelines by the Council on Environmental Quality, the environmental review of proposed projects has become more routine and smooth flowing. Procedures are now established for focusing the environmental assessment on the most significant issues and limiting the production of endlessly detailed discussions of insignificant points.

The NEPA process is triggered by a federal action which may be a federally sponsored project, or may be a federal permitting decision on a private project. In the case of siting WT's in New Hampshire, the process would be triggered and an EIS required if:

- the Navy initiated a WT installation;
- national forest lands were used; or
- a federal permit was required.

Thus, if a WT installation were initiated by a private party to be established on land outside the national forest boundary and constructed in such a manner that no federal permit was required, NEPA would not apply.

5.3.2 State Environmental Review

Some states have thought it beneficial to establish a NEPA-like process on the state level and have passed "little NEPA" laws to implement the program. New Hampshire does not have a "little NEPA" law. State level environmental review is conducted through the process defined in the siting laws (Chapters 162-F and 162-H) Facilities generating less than 5 megawatts are exempt. It would, therefore, appear

that small clusters of medium-scale wind turbines (rated power approximately 200 kilowatts) or a MOD-2 (rated power equals 2,500 kilowatts) could be installed on private land without any substantial environmental review.

5.3.3 Significant Environmental Issues

5.3.3.1 Radio Frequency Interference

Results of theoretical analysis, computer and laboratory simulations and field tests of the potential for wind turbine interference with radio signals have been summarized recently (Kornreich and Kottler, 1979). There has been no distortion detected in audio broadcasts (i.e., at AM frequencies), but wind turbines have been observed to cause distortion in television pictures and have the potential for adversely affecting microwave communication links and electronic air navigation aids.

Reflection and scattering of electromagnetic energy occurs when a direct radio wave signal hits the rotating blades of a WT. Under certain circumstances, significant interference can occur. The location of the WT with respect to transmitter and receiver (direction and distance) is the most critical factor in determing the level of interference. Blade geometry, material of construction, rotation speed, and scattering efficiency of the blades are all factors in determining the range over which interference can exist. Experimental evidence suggests that metallic blades have a much greater scattering efficiency than composite blades. (Kornreich and Kottler, 1979) Wind turbines with large, metallic blades have a greater potential for electromagnetic interference than those with small, composite blades.

Federal Communications Commission (FCC) regulations state that:

> "An incidental radiation device shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." (47 CFR 15.25)

Proper attention must be given to the locations of the existing radio and television transmitting equipment during the siting of WT's. (See Appendix A maps for locations of key radio and TV antennas as well as aircraft beacons.) Compliance with FCC regulations should assure insignificant interference with broadcasting operations.

Interference with television reception can cause objectionable video distortion in the higher channel numbers at distances up to a few kilometers from the turbine. Some of the distortion can be removed with the use of a directional antenna, and in extreme cases, cable television transmission methods could be used. (Senior and Sengupta, 1978) Remote wind turbine locations at high elevations in the White Mountains would be expected to cause minimal impact on the television watching public.

Microwave communication links would also be protected under the FCC regulations. Specification of a minimum tolerable level of interference allows the definition of a WT exclusion zone which depends on the radiation pattern of the receiving antenna, the scattering area of the turbine blades, and characteristics of the microwave link. Siting of turbines outside the exclusion zone should produce no significant interference with the operation of microwave communication links.

Radio directional information from VOR (Very High Frequency Omnidirectional Range) stations can be degraded by excessive radio frequency interference. The Federal Aviation Administration (FAA) tolerates uncertainty of .5° to 1° in the bearings derived from any particular facility. An FAA official stated that the FAA is not concerned with scattering sources farther than 5 miles away. However, sources within 3 miles are of concern, and informal steps are taken to protect the integrity of VOR stations. Apparently when the signal is contaminated such that bearing information is in error by more than 1°, notification is sent to air navigators.* These stations are expected to continue providing uninterrupted navigational data to flying aircraft if an exclusion distance of 5 miles is maintained. Only two VOR stations are found in the region of interest in this study. One station is located north of Berlin, New Hampshire, and the other is located in Concord, New Hampshire. None of the sites identified in this study fall within 3 miles of these station antennas.

5.3.3.2 Safety

The issue of WT safety has several aspects, each with its own relation to size, type, and location of the proposed development. Mechanical hazards (e.g., tower collapse or blade breakage), interference with airplane flight paths, electrical hazards, electromagnetic interference, ice thrown from blades, noise and vibration, construction hazards, etc., each impact safety differently according to the site location features such as population density in the vicinity, proximity to airports, proximity to radio equipment, etc.

The wind turbine at Grandpas Knob threw its broken blade 750 feet (Putnam, 1948). Calculations show that ice chunks could be thrown a half mile or more. A more detailed discussion of ice is given in Section 4.1. The safety implications of ice throw and blade breakage would require detailed evaluation during environmental reviews, as would all other safety issues. [Some aspects of the review (e.g., aircraft flight path interference) would already be subject to existing federal regulation (e.g., FAA Height Standards, 14 CRF 77).] Other aspects would require review on a case-by-case basis.

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*Personal communication--telephone conversations with Paul Maguire, FAA, Burlington, Massachusetts on August 30 and September 6, 1979.

Siting of turbines in relatively remote areas should minimize safety-related institutional constraints, primarily because of inherently low population exposure and the ability to control relatively large land parcels as exclusion areas.

5.3.3.3 Ecological

The ancillary facilities (e.g., power transmission lines, roads, maintenance buildings, etc.) may have ecological effects greater than those of the wind turbine itself.

Power line and road construction would result in removal of vegetation and disturbance of soil stability which could have adverse effects on streams over a wider area than where direct actions occur. These activities would be reviewed under NEPA if they were proposed for federal land, or if a Federal permit were required as, for example, in the construction of a bridge over navigable waters. EPA's water pollution control regulations would have to be followed. Careful attention to the affects of WT construction and operation on the fish and widelife population and on rare and endangered species would be required under the Fish and Wildlife Coordination Act and the Rare and Endangered Species Act of 1973, respectively. Any clearcutting of forests to provide a clean approach to the turbine for the wind power would also be subject to the same kind of review.

The effects of WT's on migratory birds and insects is an area of significant concern. Experiments reported to date have not shown conclusively that WT towers and blades are significantly more detrimental to birds than tall structures of other types, e.g., bridges, buildings, etc. However, this subject requires more thorough investigation, and some authors have suggested that eastern portions of the country might be more constrained in this regard than the open country of the West. This would be particularly true for wind turbines located in migratory bird flyways.

Investigations of microclimatological effects have not shown effects which were as large as the natural variability in such key indicators as rainfall, windspeed, temperature, and carbon dioxide level.

5.3.3.4 Other Environmental Issues

The NEPA review is comprehensive in exploring all significant issues including social and economic issues. Thus, the impact of a proposed project on historical or archaeological sites and habitats for endangered species would be reviewed in addition to consideration of such factors as aesthetics. A general observation can be made concerning the importance of aesthetic considerations for any project at higher elevations within the White Mountain National Forest. The Forest is currently managed with a high degree of emphasis on recreational (including aesthetic) uses. Any proposal which substantially alters the view shed within the Forest will be approved only with great difficulty.

5.4 Wind Rights

The issue of who owns the wind for purposes of energy extraction has been discussed in the literature, although there is little significant law on the matter. The basic issue revolves around the fact that a person who installs a WT could affect the air flow on a neighbor's property. In fact, it is possible that one person could remove substantially all the economically important wind power from air for a distance of ten rotor diameters (or more downstream) (see Chapter 4).

In previous discussions, analogies have been drawn from court cases which considered interference with television reception by newly constructed buildings, the right to sunlight, and so on. Most of the discussion is focused on areas where small parcels of land held by many owners present the potential for significant conflicts between the "wind robbers" and those who are "robbed." In the White Mountain vicinity, the issue is largely moot. Within the National Forest, it is assumed that siting decisions based on careful planning would assure adequate separation of adjacent turbines to allow maximum efficiency in harvesting the wind. Much of the high country outside of the National Forest is in relatively large parcels held by either state or private interests. To the extent that siting decisions are coordinated between adjacent owners, or made by large land holders the issue is again moot. In those cases where competition for limited space becomes significant, the issue will have to be resolved in the courts.

5.5 Financial Considerations

In line with our initial approach in this study, the financial constraints to wind power development are touched lightly.

5.5.1 Sources of Revenue

One of the major considerations affecting the decision of individual entities to undertake wind power development centers on the proposed use of the generated electricity. Different factors provide the stimulus if the purpose is self-use of the electricity or sale of the electricity. These factors are discussed in Section 6.

5.5.2 Availability of Financing

Generation of power from the wind is a capital intensive endeavor which will require availability of sufficient support from financial institutions to be successful. The amount of support necessary will be a function of the size of development contemplated. It has been noted that generally there is a distinct possibility that capitalization for certain of the configurations either may not be available at all, may not be available in adequate amounts, or may be obtainable only at prohibitive rates.

For small (less than 100 kilowatts) configurations, the WT's should be financed much as would any purchase of similar cost (e.g., $7,500 to $18,000), usually through a bank or other lending institution. For moderate size (100 to 1,000 kilowatts) configurations, the WT's should be financed like any other capital improvement. However, the financing problems faced by the electric power industry for installations greater than 1 megawatt in the 1970's (particularly by its investor-owned segment) are substantial ones. Recently, declining earnings resulting from increased fuel costs, higher interest payments on bonds, and rate increases insufficient to meet these expenses have tended to make "external" sources of financing (e.g., stocks and bonds) more difficult or more expensive to obtain. And, because of anticipated increases in electrical demand, it is often felt that the capital requirements of the industry will be very substantial until at least 1985. (George Washington University, 1979)

It may be necessary to supply some sort of federal financial support to stimulate the development of wind power in New Hampshire. This support could be in the form of direct support through low interest loans, through government guaranteed loans, or through a system of tax incentives.

5.5.3 Insurance/Liability

At the present time, the financial implications of insurance requirements and public and private liability aspects of WT installations lies in the realm of speculation. Since there is very limited operating experience with WT's, the basis for establishing reasonable insurance rates is weak. Under these conditions, rates could be offered which would be prohibitively high and could constrain development.

The owners liability for damages from negligence and nuisance claims can be reduced by providing site design features which incorporate all normal safety precautions, large exclusion distances, and perimeter fences. Standard electrical generating and transmission equipment has been the topic of litigation, but little clear guidance emerges from the cases to indicate the extent of obligations to which WT owners/operators may subject themselves. (George Washington University, 1979)

5.6 Recommendations

Significant barriers in the form of land use constraints exist to the development of wind power in the vicinity of Mt. Washington (i.e., the White Mountain National Forest). Existing federal land use controls may be altered in light of newly perceived public needs and desires, but the time frame for such changes would be long, and the procedures to accomplish such change are not straightforward. At this point, it would appear that wind power development could be accomplished without such constraints on private, and perhaps also on state owned land.

Development of wind power in New Hampshire should progress in a phased manner. The early phases should be dedicated to wind exploration/prospecting and to the location of suitable sites for pilot studies. A parallel effort focused on revision of federal land use regulations should also be undertaken. This effort would involve the establishment of wind power as a recognized "resource" amenable to management under the multiple-use, sustained-yield concepts which are applied to national forest lands. This effort would have to focus on obtaining Congressional action to amend the enabling legislation, including the Multiple-Use, Sustained-Yield Act.

Even after amendment of the enabling legislation, the road would not be clear to utilizing high elevation sites in the national forest for wind power generation. It would have to be recognized through the planning and public participation process or by Presidential fiat that aesthetic alterations of sensitive areas for the purpose of wind energy development would best serve the needs of the people of the United States. Presumably, these changes would then be incorporated in the Forest Management Plan. At this writing (August 1979), Congress is debating the President's proposal to establish an Energy Mobilization Board with broad powers designed to hasten energy development. The extent of the Board's jurisdiction (should it be established, as now appears likely) or the use of its powers regarding national forest lands is subject to speculation.

Following successful completion of pilot studies on non-federal land, the actual practical application of WT's in New Hampshire would be better understood in all of its environmental and social dimensions. If efforts to attain official recognition of wind as a resource were successful, then it would be appropriate to attempt siting a modest WT or cluster on federal land.

6.0 USEP ECONOMIC AND INSTITUTIONAL ANALYSIS

6.1 Summary of Approach

This chapter is ultimately concerned with the economic performance of wind, taking into account the value of fuel that is displaced by wind, the regulatory issues that relate to rate setting, and the effect of different ownership options.

Three different ownership options are put forward: the Navy, the utility, a third party. The economics of ownership are different in each case. The Navy as owner benefits when wind displaces co-generated electricity at its fuel price. The utility as owner benefits when wind displaces fossil fuel which is purchased at a price generally lower than what the Navy pays. The utility fuel is generally used at a higher heat rate (i.e., less efficiently) than the Navy, which uses cogenerated power. The third party as owner benefits when the utility pays a price per kwh generated which is set by the New Hampshire Public Utility Commission or the Federal Energy Regulatory Commission (such a price may be higher than the average utility fuel cost).

In this chapter it is demonstrated that the Navy, as owner, is the least economically attractive option, and is not likely to meet the Navy's cost effectiveness criterion for an investment in new self-generated capability. It is shown that a third party ownership option is to be preferred from an economic as well as institutional point of view.

In section 6.2 the institutional issues are discussed in order to show the range of economic implications that they produce.

In section 6.3 the Portsmouth Naval Shipyard is described. It is shown that most of the shipyard's electric production in the future is expected to be via cogeneration with purchases of power from the utility diminishing. This projection has implications for the value of wind power when the Navy is owner.

In section 6.4 the historic cost of fuel for electric generation to the Navy and to the utility is examined in order to obtain a range of expected future price. The value of wind to each user is then computed using economic and institutional considerations previously discussed. Finally, the cost of wind energy is examined and conclusions reached as to its economic attractiveness.

6.2 Utility and Ownership Issues

6.2.1 Federal/State Utility Requirements

Recent policy developments at the Federal level have led to a variety of measured aimed at stimulating the development of solar, wind and other nonfuel alternative energies. Many of these have been embodied in the recently enacted National Energy Act (NEA). Of

particular interest is the part known as PURPA, (Public Utilities Regulating Policies Act), in which a utility can be required to pay a set rate for solar, wind, or hydro source power fed into the grid system, as described below. Reinforcing PURPA in New Hampshire is the Limited Electrical Producers Act, within which a precedent for pricing electricity above the utility's average incremental cost appears to have been established. The implications of these acts are described herein.

6.2.2 Public Utility Regulatory Policies Act

PL 95-617 of the National Energy Act is known as the Public Utility Regulatory Policies Act of 1978 (PURPA). Section 201 of this document defines a "small power production facility" to include "biomass, waste, renewable resources, or any combination thereof" under 80 MW capacity. Thus, any wind turbine cluster (i.e., farm) contemplated herein would qualify.

Section 202, would require that the "small facility" be connected to available transmission and that provision be made for the sale or exchange of electricity by order of the Federal Energy Regulatory Commission (FERC).

Section 203, would require the electrical utility to provide a wheeling service to the small producer, including any enlargement of transmission capacity necessary to provide such services by order of FERC. (This means that the small producer may be remote from his customer, with power wheeled on the utility grid.)

Section 204, however, prevents FERC from promulgating orders as described above unless the following conditions are met:

(1) The order "is not likely to result in a reasonable ascertainable uncompensated economic loss for any electric utilities..."

(2) The order "will not place an undue burden on an electric utility..."

(3) The order "will not unreasonably impair the reliability af any electric utility affected..."

(4) The order "will not impair the ability of any electric utility affected to render adequate service to its customers."

Section 210 requires that FERC issue rules pursuant to the small producer-utility interface including rates for purchase by the utilities. "No rule prescribed...shall provide for a rate which exceeds the <u>incremental cost</u> to the electric utility of alternative electrical energy."

Thus, even in the absence of state law, PURPA assures that a qualifying small electrical producer, such as an owner of a wind turbine cluster, can interconnect to the local utility and obtain a price for electricity, if certain conditions are met.

[From the point of view of the Portsmouth Naval Shipyard, it is noted that the cited sections of PURPA also apply to qualifying cogenerators. Thus, the Naval Shipyard may qualify to sell surplus cogenerated electricity to the Public Service Company of New Hampshire (PNH); the local electrical utility. Since this report is limited to the feasibility of wind power, the issues related to the cogeneration were not pursued.]

Limited Electrical Energy Producers Act of 1978 of New Hampshire (RSA-362-A). Referred to as RSA 362A, the Act defines a limited producer as one whose capacity (excluding nuclear or fossil fuels) is less than 5 MW. Such producers "shall not be considered public utilities and shall be exempt from all rules, regulations, and statutes applying to public utilities."

For qualifying producers (1)", the entire output of electrical energy..., if offered for sale, shall be purchased by the electric public utility..." and (2)" Public utilities...shall pay a price per kilowatt-hour to be set from time to time by the public utilities commision."

On April 18, 1979, the Public Utilities Commission issues the first Order under the Limited Electrical Producers Act. It ordered PNH and the New Hampshire Electric Cooperative to pay the Franklin Falls and Goodrich Falls Hydroelectric Corporation, respectively, 4¢/kWh for run-of-the-river production, and 4.5¢/kWh for dependable production based on storage.

The Order cited the definition of "incremental cost" for PURPA, and indicated a lack of agreement as to its precise meaning, which emerged at the Commission's hearings of October 12th and November 30th, 1979. PNH mentioned that in 1978, the "average incremental cost was 2.256¢/kWh (down from 2.331¢/kWh in 1975). The Cooperative, however, "offered the opinion that it means not only the cost of the next kilowatt-hour to be bought but also should include the total cost per kilowatt-hour for the next plant that has to be built some time in the near future." For example, it was stated that power from the Seabrook Nuclear Power Plant now under construction, when available in 1983, would cost 4.5¢ to 5.0¢/kWh.

The Order acknowledges the uncertainty of the definition of "incremental cost" under PURPA and states that it will "re-evaluate this decision after the promulgation of the FERC rules and regulations pertaining to PURPA." The resulting Order to pay 4.0 and 4.5¢/kWh appears to have been largely influenced by the Cooperative opinion cited above. The Order also says that the finding was based on the legislative

intent of PURPA and RSA 362A. In an interview, conducted by Arthur D. Little, Inc. with the New Hampshire Public Utilities Commission (PUC), Michael Love, Chairman, said that the PUC definitely encourages wind and solar, and that it interprets the Acts to mean that there is an intent to weigh the evidence at hearings on the side of incentives for limited electrical producers.

It would be speculative to predict the price to be paid for a specific wind facility by the local utility. It can be assumed, however, that a wind turbine cluster will quality under PURPA and RSA 362-A, and that the Commission is not likely to set a price lower than about 2.2¢/kWh.

6.2.3 Utility Interface

From the utility point of view, there appears to be no significant barrier to implementing an interface between a wind facility and the electric utility in New Hampshire. This issue was discussed with the New Hampshire utilities, and with the New England Power Exchange (NEPEX) as described below.

6.2.3.1 Utility Viewpoints

In an interview with personnel from the Systems Planning and Load Research and Forecasting sections of the Public Service Company of New Hampshire (PNH), the major utility interface concerns were identified as:

(1) Safe connection. No feedback can be permitted through a line on which people may work.

(2) Fair price. Wind power, it was stated, makes no contribution to the capacity of the grid, and the value of the output varies with time. The simulation of fuel cost savings is acknowledged as a rational basis for getting at the real value of wind power.

In an interview with a manager of the New Hampshire Electrical Cooperative, an opinion was stated that a fair price should include a capacity credit for wind.

In an interview with managers of NEPEX, load management of wind power transients were not seen as an issue at the grid level. Even a 100 MW fluctuation within an hour would not be significant. Winter peak loads can vary as much as ± 2000 MW (total system capability is about 22000 MW).

6.2.3.2 Wheeling

Both PURPA and RSA 362-A require that utilities wheel power on behalf of a limited electrical producer, and establish a fair rate for doing

so. Since the wheeling issue has not come up for consideration before the NHPUC, there is no precedent as yet. However the issue was discussed with PNH and NEPEX.

PNH reports transmission expenses for 1978 as .096¢/kWh sold. Responding to the case of the U.S. Navy generating power in the Mt. Washington area to be applied to the Portsmouth Naval Shipyard, PNH does not feel that PURPA intends that such power be wheeled in a physical sense, as this may impact on the system-wide economic dispatch in an adverse way.

Two methods for computing wheeling charges (regardless of physical configuration) would be:

(1) Postage stamp rate - a uniform rate anywhere in the grid independent of distance. A small producer would not provide reciprocity in the grid and should not be eligible.

(2) Dedicated line - charge proportional to the capacity used and based on the capital cost of the line.

Generally speaking, PNH feels that the wheeling issue is complicated and would prefer to deal with the issue of a fair price to be paid a power producer rather than a combination of credit to a remote user's electric bill combined with a wheeling charge.

NEPEX reports that 1978 wheeling charges come to 0.04¢/kWh between member companies. This is to be viewed as a minimum rate for large scale transmission and would not apply to a limited producer. NEPEX felt that wheeling rates in this instance should be computed following the "dedicated line" assumption.

A PNH executive expressed the opinion that the wheeling provision, of RSA 362-A would not apply to the Portsmouth Naval Shipyard since it is physically in Kittery, Maine, and not in New Hampshire. A member of the NHPUC confirmed that the jurisdiction for utility rate setting normally resides with the state of the customer rather than with the state of the utility. Also, since the negotiated contract between the Navy and PNH was evidently not filed in New Hampshire, it would appear that the state would not have jurisdiction when it came to resetting the rates under the existing contract. Whatever the jurisdictional issue, it would appear that PURPA would require a mechanism for wheeling and for compensation, if the "qualifying producer" petitioned FERC.

Since the output of the wind facility in the mountains does not have to be physically wheeled, the wheeling issue is merely an administrative matter, and part of a contract negotiating process. Since the costs of transmission on a ¢/kWh basis are small compared with the price of the

electricity itself, the wheeling rate to be negotiated is not expected to be a significant barrier in the economics of a wind facility.

6.2.4 Wind Facility Ownership Options

Three ownership options are considered: the Navy, the Utility, and a third party. Each have different regulatory and economic implications as summarized on Table 6-1 and discussed below.

6.2.4.1 The Navy as Owner

The Navy as an owner of WT's has two choices: (1) The Navy can provide a direct linkage to the wind facility, reducing the total load to be met by a combination of cogeneration and utility supply; (2) the Navy can use the utility to wheel wind power from any location in New Hampshire.

The first choice requires a wind facility at the Portsmouth Naval Shipyard, or in the neighborhood with a direct line to the shipyard. Wind power would reduce the draw on the utility to the extent possible, but would more likely reduce cogenerated electricity since the purchase of utility power will generally be minimized because it is less economic than cogeneration. (See Section 6.3.)

The second choice involving wheeling has somewhat more complex implications.

(1) Displacement of utility supplied power is preferred. But since utility supply will be minimized to the extent possible by cogeneration, the opportunity to displace utility supplied power will be minimal.

(2) Displacement of cogenerated power requires the wheeling of wind power from the remote site using the utility grid. Thus, the draw on the utility is actually increased to the extent that cogenerated electricity is displaced.

(3) Part of the Navy's electrical power is used for submarine testing and needs to be regulated to 440 V $\pm$ 10 V. The utility grid voltage varies between 12,900 V to 14,000 V and cannot be transformed down to the required range within 10 V tolerance.

6.2.4.2 The Utility as Owner

In this case the Navy has no role. The utility invests in a wind facility taking advantage of all available tax credits and development incentives. It simply recovers the investment through fuel savings and any capacity credit savings (if possible) elsewhere in the system. There are no wheeling or rate setting issues involved.

Table 6-1

SUMMARY OF OWNERSHIP IMPLICATIONS

OWNER	BASIS FOR BENEFITS	MAJOR PROBLEMS	ROLE OF NAVY	IMPLICATIONS OF RISK	ECONOMIC ATTRACTIVENESS
Navy	Direct fuel displacement in cogeneration.	Minimum opportunity to displace fuel or utility supplied power. Voltage regulation. Complex wheeling issue.	Owns and operates facility.	U.S. Taxpayers	Very little, if any.
Utility*	Direct fuel displacement in equipment dispatch.	Reluctance to innovate risky new technology.	No role.	Utility Customers	Promising us a demonstration.
Third Party	Price fixed by the PUC.	Project financing. Relationship to utility.	Possible role as remote customer.	Private Investors	May be made economically attractive to the investor.

*Where appropriate for this study the utility is assumed to be privately owned.

For this study, it is assumed that the utility is privately owned.

6.2.4.3 Third Party as Owner

A third party is presumed to be either an independent tax paying entity that seeks to make a profit on an investment in a wind facility, or a suitable public corporation. It would sell power to the utility at a rate fixed by the Public Utility Commission under the Limited Electrical Producer's Act and PURPA. Based on precedent, this rate is likely to exceed the value of displaced fuel to the utility.

The role of the Portsmouth Naval Shipyard in this case, could be as a contract customer who purchases power to be wheeled by the utility. However, the owner would want to receive at least the same price from the Navy under the contract, as it would receive from the utility under a PUC order. Since this price is likely to exceed the Navy's willingness to pay based on the value of fuel saved in cogeneration (see later section), we conclude that the Navy has no role in the third party option.

6.2.4.4 Implications of Risk

An investment into a wind generating facility has an associated risk, which is different for each owner option.

Navy Risk

The Navy is constrained to operate as economically as possible. Given the uncertainty in final project cost, and amount of delivered output, the Navy would be risking a cost overrun at reduced benefits. It also risks increasing the dependency on PNH in the case of wheeled power. This is a higher risk approach because of the uncertain condition of the submarine (i.e., underwater) cables connecting the Base to the utility (described by Navy Yard personnel) and the problem of voltage regulation previously mentioned.

Utility Risk

The utility takes on the same risk of an overrun and of reduced benefits as the Navy. Since the utility is contracted to minimize operating costs, it may seek to avoid a project that is considered financially risky. Such risks are ultimately borne by the customer.

Third Party Risk

The third party takes on the same financial risk as other owners. However, the risk is limited to the equity holders and creditors who invest with the specific intention of taking risks. Failure of the venture has no economic impact on the utility. Also, the law (PURPA, RSA 362-A) favors the third party in requiring a utility to purchase the output at a rate that provides an incentive to alternative

power development.

6.3 The Portsmouth Naval Shipyard

6.3.1 General Description (See Portsmouth Naval Shipyard, 1978)

The Portsmouth Naval Shipyard is geograhically located in Kittery, Maine but has a Portsmouth, New Hampshire address. According to the Master Plan, "The Portsmouth Naval Shipyard performed one major service to the operating fleet: overhaul, conversion, and repair of nuclear propulsion fleet ballistic missile, and attack submarines." Supporting activities are performed by the Marine Barracks, Regional Medical Clinic,Navy Printing and Publications, Dental Clinic, and several other units.

The Base encompasses 278 acres of land, including the non-contiguous 25 acre family housing site. There are six submarine berths (of varying service capability), plus berths for yard and service craft. In addition, there are 376 buildings and structures with 3,560,000 sq. ft. of floor space.

The Navy has not considered the Base itself as a site for wind, and there is no history of wind measurements at the base. (There are records at Pease Air Force Base in the vicinity.) Reference to the site map (Figure 6-1), suggests Clarks Island as a possible site for a wind facility.

6.3.2 Electric Energy Needs

Data provided by the Shipyard indicate that 1978 electrical consumption was about 60 x 10^6 kWh, and is expected to range between 73 and 82 x 10^6 kWh in the future. The 1978 daily peak varies from 11 to 14 thousand kva, and is expected to reach 18-20 thousand kva in the near future (.9 power factor).

The load duration curves for the period April 1, 1975 to March 31, 1976 are shown on Figure 6-2. The lower curve, "purchased power" was provided by PNH. The "generated power" curve is Navy cogenerated power. The need for additional capacity is clearly illustrated.

Personnel at the Portsmouth Naval Shipyard provided operating records for the year 1978, consisting of daily and hourly electric generation, purchase, and steam loads. The load duration curves, based on this diagram are shown in Figure 6-3. Based on the figure, the load duration curves have not changed significantly over the past two years.

6.3.3 Electrical Energy Supply

The Naval Shipyard currently has two 3500-kw double extraction turbine generators. The peak output of both turbines is insufficient

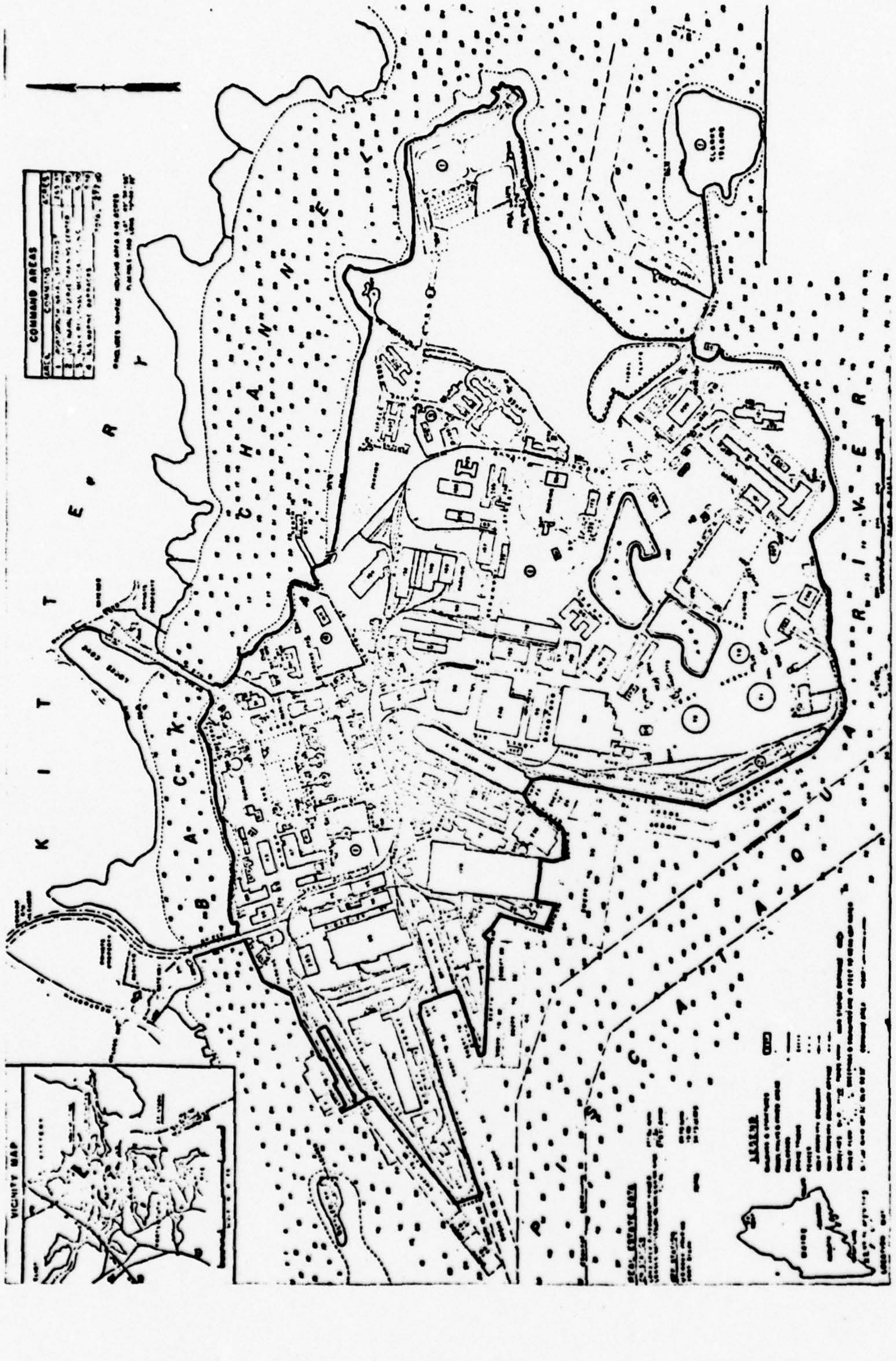
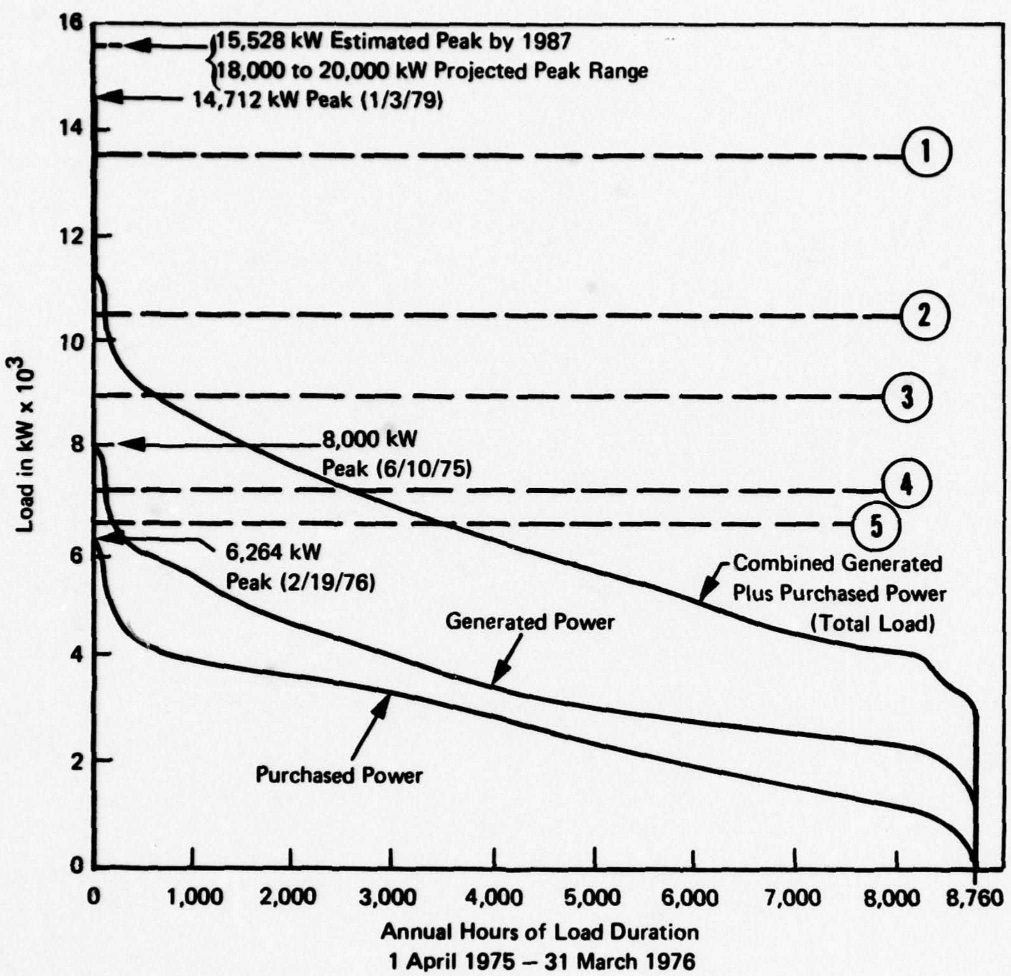


FIGURE 6–1 U.S. NAVAL ACTIVITIES
SEAVEY ISLAND, KITTERY, ME.
EXISTING CONDITIONS MAP – NOV. 1976



Legend:

1. Proposed Firm Generating Capacity with Utility Outage (includes reactor losses)
2. Present Capacity with One Generator Out of Service (includes reactor loss; utility P.F. assumed = .9)
3. Utility Power Capacity if Available (assume .9 power factor) (This cannot be considered reliable capacity.)
4. Utility Assured Power Capacity (assume .9 power factor)
5. Present Firm Capacity with Utility Outage (includes reactor losses)

Source: Portsmouth Naval Shipyard.

FIGURE 6–2 LOAD DURATION CURVES

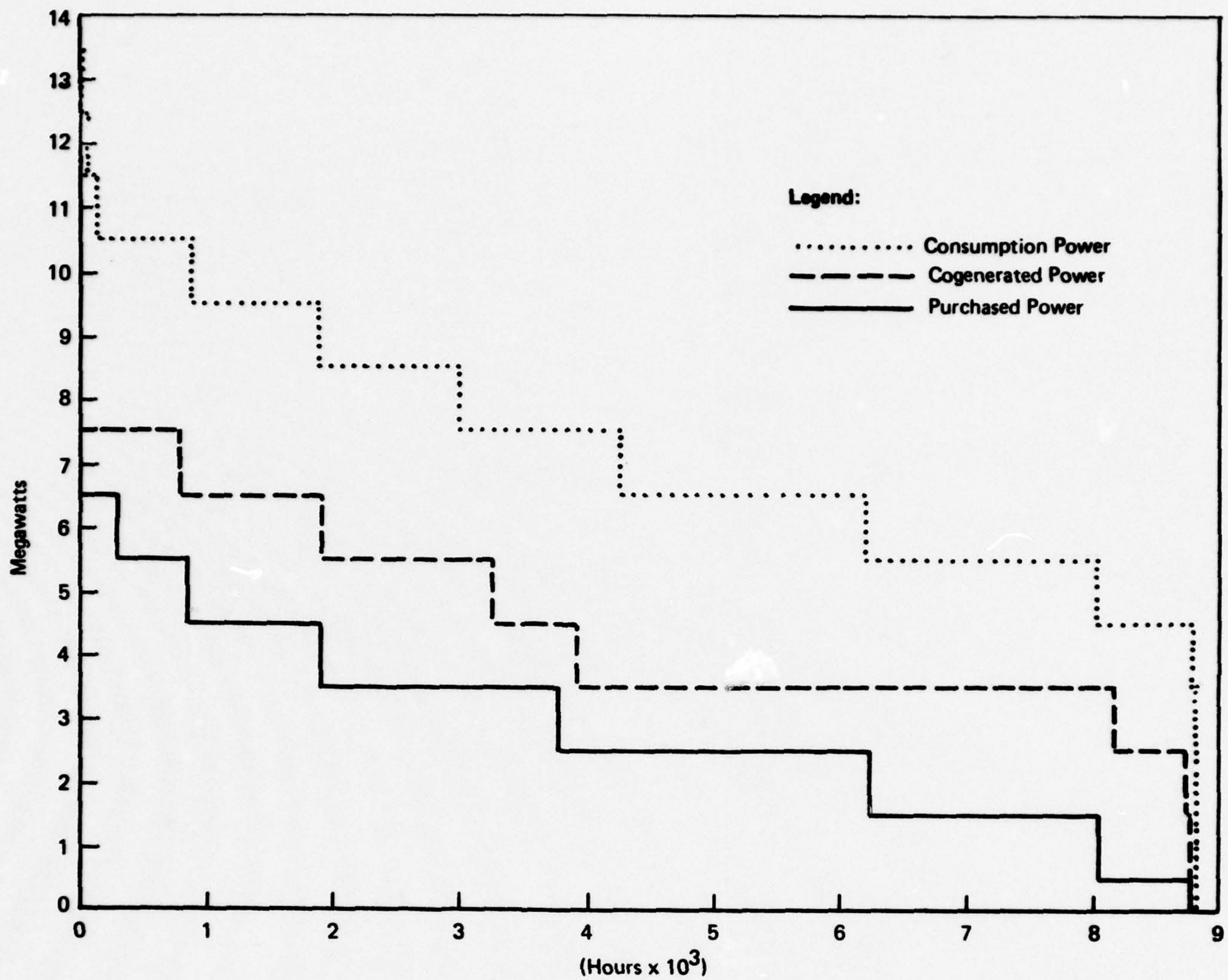


FIGURE 6–3 LOAD DURATION CURVES, JAN. 1, 1978–DEC. 31, 1978

to meet the future peak demands shown in Figure 6-2. The turbines are 30 years old and are considered reliable.

The Shipyard currently has a contract with PNH to supply a maximum of 8000 kva, and if available and prearranged, "additional capacity in excess of 8000 kva and up to a maximum of 10,000 kva" (Portsmouth Naval Shipyard, 1973).

Utility power is supplied via two submarine cables owned by PNH the contract supply for which is contingent upon the cables being in service. It has been suggested that this clause reflects uncertainty about cable reliability in the future. At the present time, the shipyard attempts to limit the cable load to 5,000 kw (at .9 power factor).

To meet its current and future needs, the Shipyard is now installing an additional double extraction turbine of 7,500 kw capacity. When operational, this unit will more than double the shipyard peak capability to 15 mw, enabling the shipyard to meet anticipated peak loads until the early 1980's without the need to purchase utility electricity.

6.3.4 Future Electrical System Operation

The results of electrical system operation (as between cogenerated and purchased electric energy) for the existing systems are shown for 1975-76 and the 1978 periods in Figures 6-2 and 6-3 respectively. Cogenerated power is seen to exceed purchased power. According a recent study (Pope, Evans & Robbins, 1977) of Shipyard energy operations with the 7500 kw unit installed "...at some point as (price of fuel per gallon) drops, these results suggest that total self-generation is still more economical than any purchase/self generation combinations."

In an interview with the principal author of the study, an opinion was expressed that the steam load at the shipyard is so high, that it pays to cogenerate virtually all of the time. Accordingly, it will be assumed for purposes of analysis herein that the Base will normally cogenerate, using the utility as a source of backup supply only when equipment is down.

6.4 Economic Analysis

6.4.1 The Price of Fuel and Electricity

Figure 6-4 shows the history of fuel prices paid by the Portsmouth Naval Shipyard as compared with steam oil purchased by PNH, U.S. wholesale prices of light fuel oil, and wholesale crude oil.

Before 1972, the price of shipyard fuel oil was less than 5.6¢/gallon. Beginning in 1973 fuel oil prices began an upward spiral which appears to continue after a leveling period from 1974-1976. The most recent price quoted by the shipyard is 42.53¢/gallon paid on July 14, 1979.

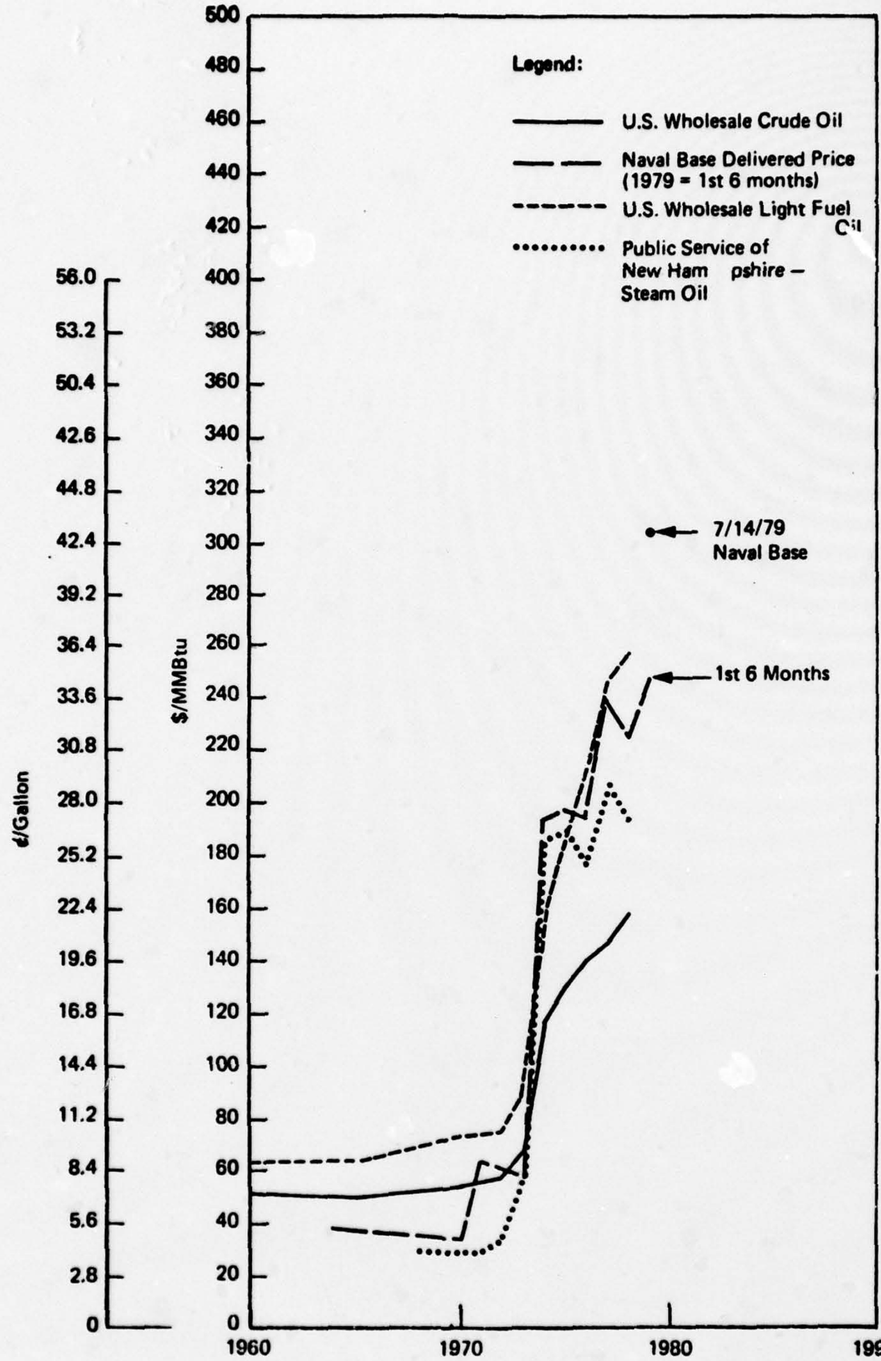


FIGURE 6–4 HISTORY OF FUEL OIL PRICES

The annual rate of growth in fuel prices for the shipyard has been very large. Table 6-2 shows an annual average of 31.12% over a 5 year period and 20.54% over a 10-year period. The utility's cost of steam oil has grown at a slightly lower average rate during the period 1973-78, and at a still lower average rate when all utility fuels are factored in.

Table 6-2

FUEL AND ELECTRIC COST GROWTH RATES (%)

	1973-1978	1968-1978	1964-1978
Utility Steam Oil(2)	27.26	20.62	---
Utility All Fuels(2)	25.90	18.63	
Navy Fuel Oil(1)	31.12	20.54	13.66
Electric Customer(2) Service Cost	15.72	12.38	
General Rate of Inflation	8%	6%	---

Sources

(1) Data supplied by Portsmouth Naval Shipyard.
(2) Data supplied by Public Service of New Hampshire.

The cost of electricity to the utility customer is somewhat attenuated by the face that fuel, until relatively recently, has been a smaller proportion of the total cost of electric service. In 1968, PNH reported that only 20.5% of revenues went to fuel purchases. By 1978, the proportion more than doubled to 45.1%, having reached almost 50% in 1977. Clearly, in the future as fuel costs continue to rise, there will be less attenuation in customer cost.

6.4.2 The Cost of Wind Power

Recent cost estimates from Department of Energy large wind turbine generator program are reported for various machines (Ramler and Donovan, 1979). The capital costs of prototype units (second unit costs) are as follows:

	Cost (1977 $)	Rating
MOD-OA	8050 $/kw	200 kw
MOD-1	2700 $/kw	2000 kw
MOD-2	1350 $/kw	2500 kw

The 100th production unit of the MOD-2 is projected to cost only $858.50/kw installed, exclusive of land costs. The 100th production unit of a 200 kw advanced design is projected at $1014/kw (NASA, January 1979). In addition, operating and maintenance costs for the MOD-2 can vary from 1% of installed cost in a 25 unit cluster to 3% for a single unit (Ramler and Donovan, 1979).

Figure 6-5 shows the cost of wind generated electricity as a function of wind speed for the 2nd prototype units, while Figure 6-6 displays the results for the mature MOD-2 unit (Ramler and Donovan, 1979).

For comparison purposes, in 1977 the average cost of energy (COE) to PNH residential customers was 4.74¢/kWh. By 1978 the cost had grown to 5.57¢/kWh. From a generating viewpoint, PNH expended 1.76¢/kWh on fuel in 1977 and 1.89¢/kWh in 1978.

From this comparison, it would not appear that any of these second unit wind turbines can produce power cheaper than the utility's fuel cost. The MOD-2, at an 18 mph annual average wind site, however, produces at 5¢/kWh, only slightly higher than the 4¢/kWh set by the PUC for intermittent low head hydro. When the MOD-2 reaches maturity, it will be economically attractive as shown in Figure 6-6, particularly if fuel costs continue to escalate.

6.4.3 The Value of Wind Power

6.4.3.1 Theoretical Basis

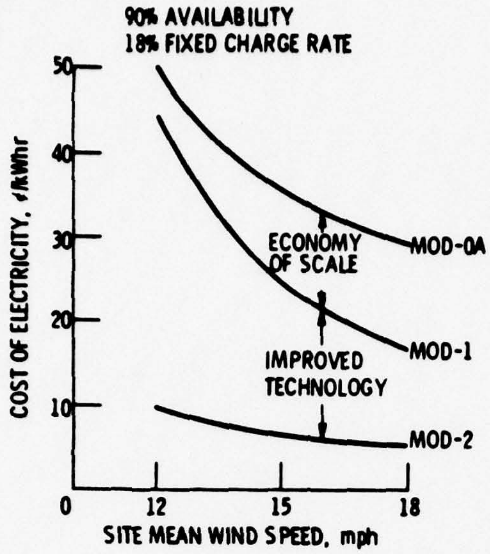
The breakeven cost is defined as the amount one can spend for a wind installation and exactly breakeven at a specified discount rate (i.e., rate or return).

For a user who pays <u>no taxes</u>:

$$C = Y_o\left[\frac{(1+k)^n - 1}{k\,(1+k)^n}\right] - C\,(f)\,\left[\frac{(1+s)^n - 1}{s\,(1+s)^n}\right] \qquad (6\text{-}1)$$

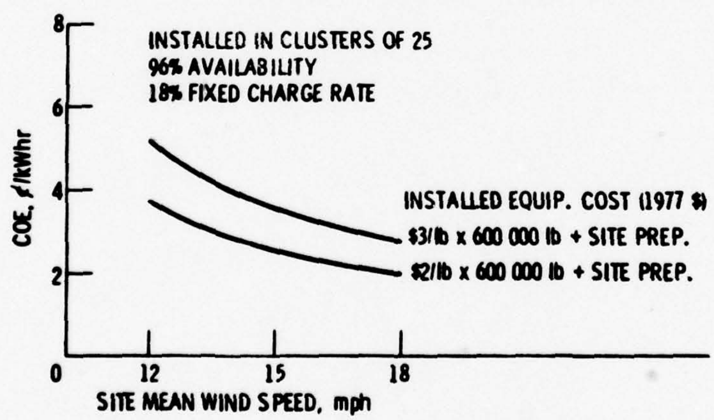
C = breakeven cost (i.e., present value of the sum of net benefits over project life).

$$k = \frac{1+s}{1+r} - 1$$



Source: Ramler and Donovan, 1979.

FIGURE 6–5 COST OF ELECTRICITY FOR 2ND PROTOTYPE UNITS



Source: Ramler and Donovan, 1979.

FIGURE 6–6 COE FROM CLUSTER MATURE MOD-2 WT's

s = discount rate

r = fuel escalation rate (net above inflation)

n = project life

f = fraction of C assumed to be annual operation and maintenance (O & M) costs (i.e., levelized O & M cost)

Y_o = dollar value of fuel saved in a single year

We assume that f = .03, n = 20 years, and s = .10:

$$C = \frac{Y_o}{1.2554}\left[\frac{(1 + k)^n - 1}{k\,(1 + k)^n}\right],\quad k = \frac{.1 - r}{1 + r} \qquad (6\text{-}2)$$

Figure 6-7 is a nomogram encompassing the above analysis of breakeven cost.

The specific wind curve of the upper left quadrant comes from data reported in Ramler and Donovan (June 1979). The two lower quadrants are simply linear relationships to be used when wind displaces fuel. When wind power can take credit directly on a ¢/kWh basis (e.g., by displacing electricity at a customer's meter) these lower quadrants are bypassed.

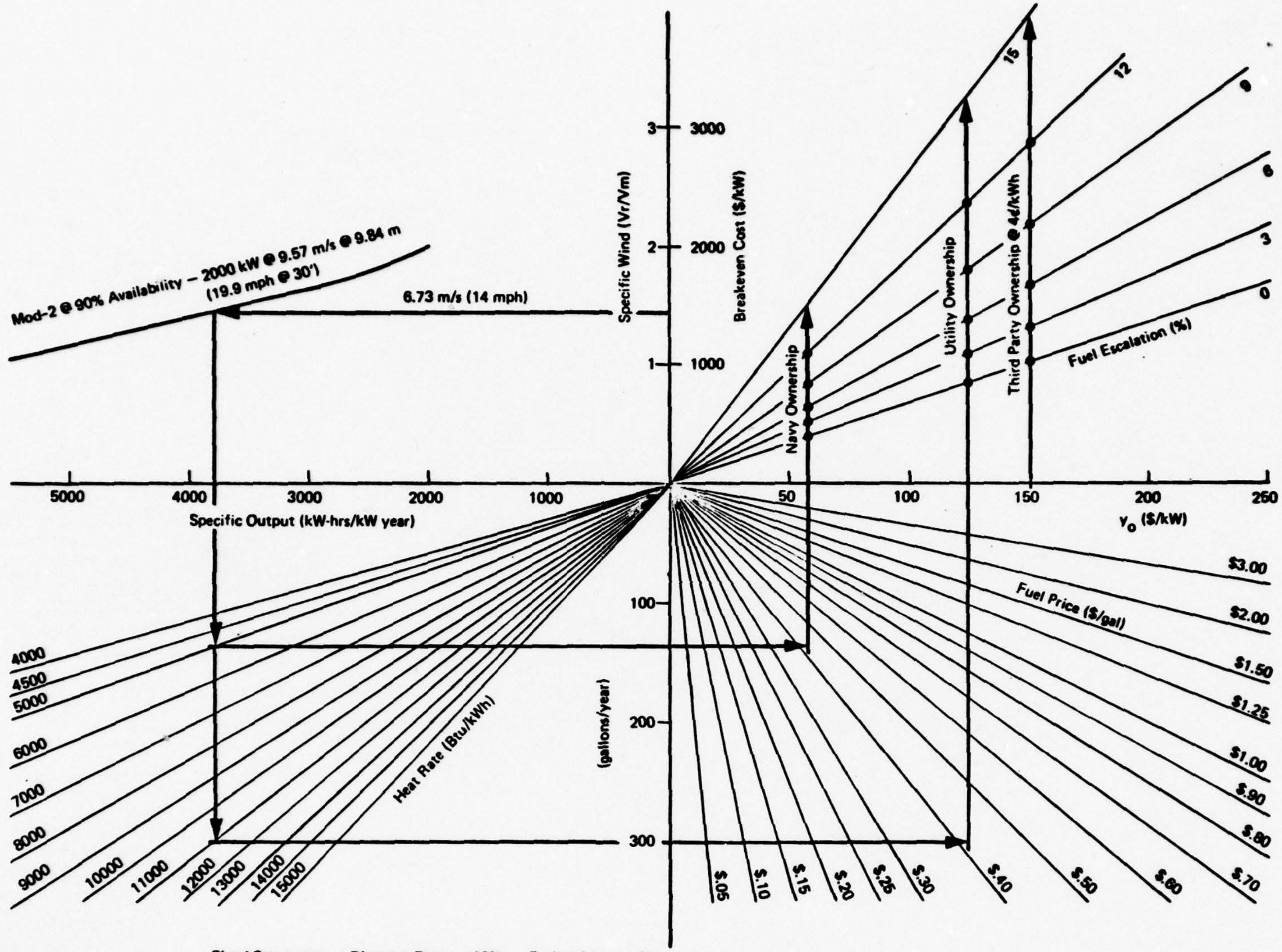
Finally, the upper right quadrant shows solutions to equation (6-2) for a range of Y_o up to \$250/kw, and a range of fuel escalation rates up to 15% above inflation.

6.4.3.2 Example of Wind Power Economic Computation Using Nomogram

Figure 6-7 shows how one can compute breakeven cost graphically from a knowledge of wind speed, rated speed, heat rate, and fuel cost.

For example, a MOD-2 machine is rated at 2.5 mw at a wind speed of 8.9 m/s (19.9 mph) at a 9.1 m (30 foot) height, and we assume it is placed at site with an average wind speed at 6.73 m/s (14 mph). It produces 3800 kw-hrs/kw-year. Using 5000 BTU/kWh as the heat rate of Naval Shipyard generation units when cogenerating, each installed kw displaces 138 gallons of fuel per year at an estimated base price 43¢/gallon. The range of breakeven costs is \$400/kw (for 0% fuel escalation)to \$1500/kw (for 15% fuel escalation).

If fuel is displaced at a heat rate of 11,000 BTU/kWh, corresponding to that reported by PNH, and a fuel price of 43¢/gallon is used again (historically, PNH has paid a few cents less than the Navy), the breakeven range is \$820/kw to \$3300/kw.



Fixed Parameters: Discount Rate s = 10% Project Life n = 20 years
O&M = 3% x Breakeven Cost
140,000 Btu/gallon

FIGURE 6–7 NOMOGRAM FOR COMPUTING BREAKEVEN COSTS OF WIND TURBINES

These results by definition are for a user of wind energy who pays no taxes. This is the case for the Navy as owner.

For the utility as owner, when fuel is saved, tax deductable operating expenses (e.g., fuel) decline. However, the utility receives an investment tax credit for the WT facility and may in the future receive additional incentive credits. We assume here that the net effect on the operating and capital cost sides is zero. The effect of the assumption is to overestimate the breakeven cost (i.e., a conservative assumption). No distinction was made here between a publicly owned and a privately-owned (i.e., investor-owned) utility.

Finally, for the third party as owner, there will be investment tax credits and, in the future, there may be additional incentive credits. There will also be tax deductions associated with the costs of operating WT's. Thus, if the price which the utility pays the privately-owned (i.e., third party) per kwh is assumed to increase at the same rate as the utility's fuel cost, the effect of neglecting taxes is to underestimate the breakeven cost. In Figure 6-7 the value of $150/kw for the third party ownership curve is computed as the product of 3750 kWh/kw-year multiplied by a price of 4¢/kWh for the energy.

6.4.3.3 The Future of Fuel Prices - Choosing an Escalation Rate

The value of the investment is very sensitive to fuel escalation rates. As seen in Section 6.4.1, fuel escalation rates over a ten year period, including the impact of the 1973 oil embargo, have been very high, far in excess of the general inflation rate.

Local utility planners have not normally included a fuel escalation cost in excess of inflation. For example, the New England Power Pool (NEPOOL) used 6.2% for cost increases of labor, materials, and fuel beyond 1980 (NEPOOL, 1977). The New York Power Pool used 6.5% for oil to 1990 and 7.0% beyond 1990 (NYPP, 1978).

Recent studies, such as that done by the MITRE Corporation (March 1978), in evaluating the economic potential of solar energy, used real utility fuel oil escalation rates (in excess of inflation) of 1.6%, to 1990 and 2.5% thereafter for the "recent trends scenario." Upon analyzing the implications of the National Energy Plan (NEP), MITRE used 6.1% to 1985, and 2% thereafter as the "NEP scenario." In the process heat sector, however, MITRE's "NEP scenario" assigned an 18.0% real oil price escalation from 1978 to 1980, and 2% thereafter. In addition, a study done by the JBF Scientific Corporation (JBF, January 1979) projecting solar electric markets, used two fuel escalation scenarios of 3% and 6% respectively (net of inflation), but indicated a preference for the lower figure for projections and planning.

With this as background, we feel that a real escalation rate of 3% (i.e., net of inflation) between now and the end of the century can be used for planning purposes. In view of 10-year escalation histories (Table 6-2) being as high as 14%, 3% to 6% fuel escalation rates above inflation would appear to be a reasonable if not conservative range of assumptions for a 20 year period.

6.4.3.4 Summary Comparison of Example Costs with Value

Table 6-3 summarizes the results for the example value analysis. Clearly, the Navy as owner does not break even (i.e., the project's value is less than the installed second unit cost). At a 6% fuel escalation rate (net of inflation), only the third party has a break-even cost which exceeds the second unit installed cost of a WT. This conclusion follows from the assumption that the 4¢/kWh price previously set by the N.H.P.U.C. will prevail, and that the facility's cost will be those of the second unit MOD-2 wind turbine generator.

The utility as owner does not achieve an adequate cost unless the fuel escalation rate exceeds 6%.

This example suggests third party ownership as the preferred mode from an economic viewpoint.

Table 6-3

COST AND VALUE COMPARISONS FOR THE MOD-2 WT AT A 6.3 m/s (14 mph) SITE

(1979 $)

Ownership Option	Heat Rate (BTU/kWh)	Initial Unit Fuel Price	Value of Project Per kw		
			r = 0%	r = 3%	r = 6%
Navy	5,000	43.0¢/gallon	400	500	650
Utility	11,000	43.0¢/gallon	840	1100	1400
Third Party	--	4¢/kWh	1010	1320	1700

Notes:

(1) Above values to be compared with $1566 per kW installed for the second unit and $996.00 for the 100th production unit.
(2) Historically the utility has paid less for its fuel than the Navy, it is assumed that each pays the same price for fuel in the example portrayed in Figure 6-7 and summarized above.

These sample results, it is stressed, represent an approximation. They are not a substitute for the more rigorous economic performance analysis which would be part of a complete design study. The purpose of the example was to illustrate the method of analysis, and to suggest a preferred project ownership mode.

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APPENDIX A

WT SITING MAPS FOR CENTRAL AND NORTHERN NEW HAMPSHIRE

Three maps are presented in this Appendix (Figures A-1 through A-3) which cover the areas illustrated in Figure 1 to the Executive Summary of this report. The maps are intended to be useful in siting future WT's in the central and northern regions of New Hampshire. With this goal in mind, the maps and associated plastic overlays contain the following information:

- Distance scale
- Key roads and highways
- Major electric utility powerlines, their ratings (in a legend), and associated substations and generating stations.
- Potential WT sites
- Antennas which may be susceptible to WT electromagnetic interference
- Roadless Area Review and Evaluation (RARE II) regions
- U.S. Forest Service Management Areas

The legend for all maps is contained on the bottom of Figure A-3. The U.S. Forest Service Management Areas are shown for the two areas of the White Mountain National Forest (WMNF) on the blue overlays to Figures A-1 and A-2. These area are classified according to the designations in the lower right corner of the legend. The RARE II areas, which exist only in the more southerly and portion of the WMNF, are shown in the red overlay to Figure A-2. The RARE II area consist of the Wilderness areas (NF033 and NF064), the areas recommended for Wilderness (9064, 9066, 9067, and 9072), and the areas recommended for further planning (9068, 9069, 9073, 9074, 9075, and 9076).

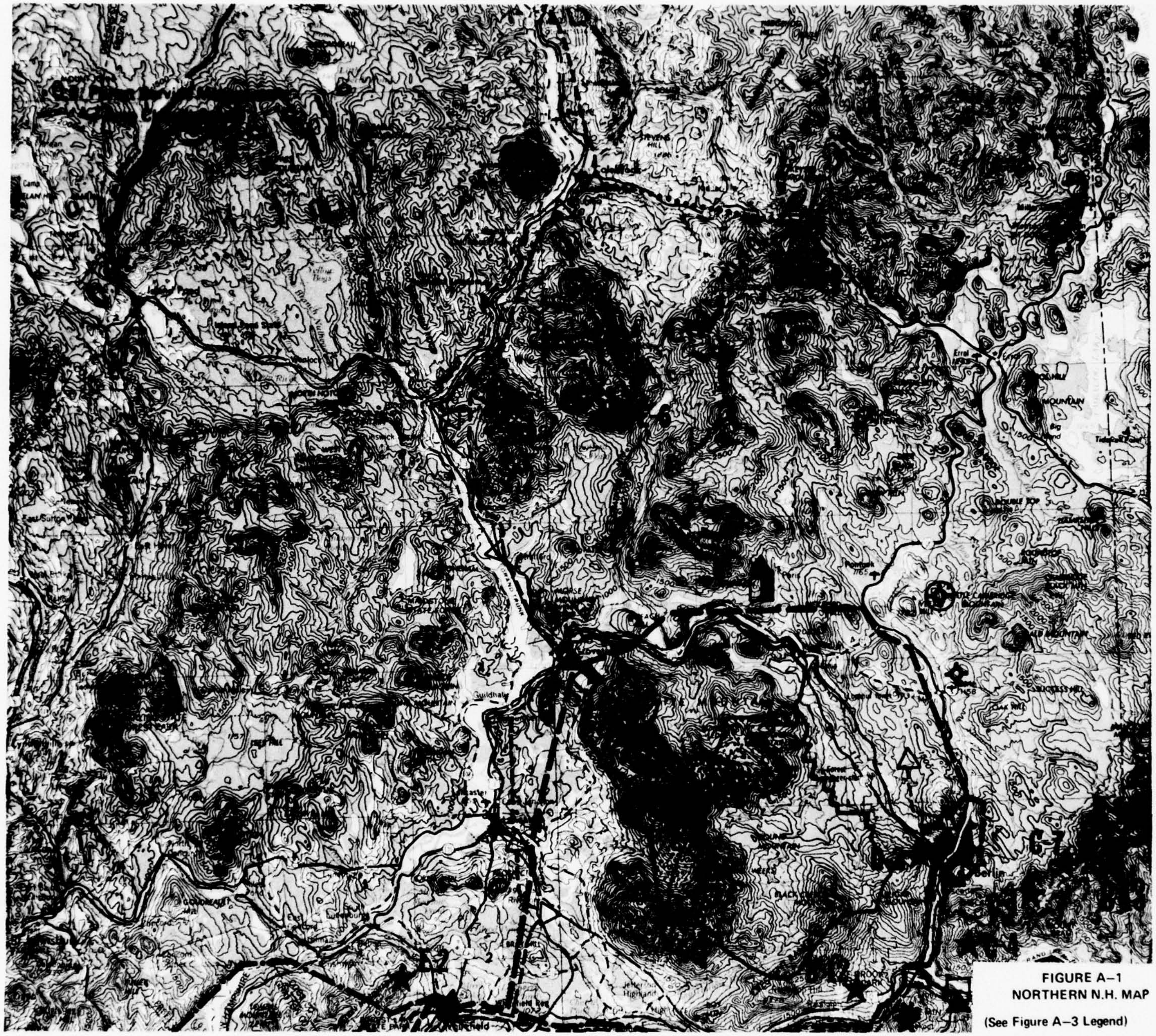
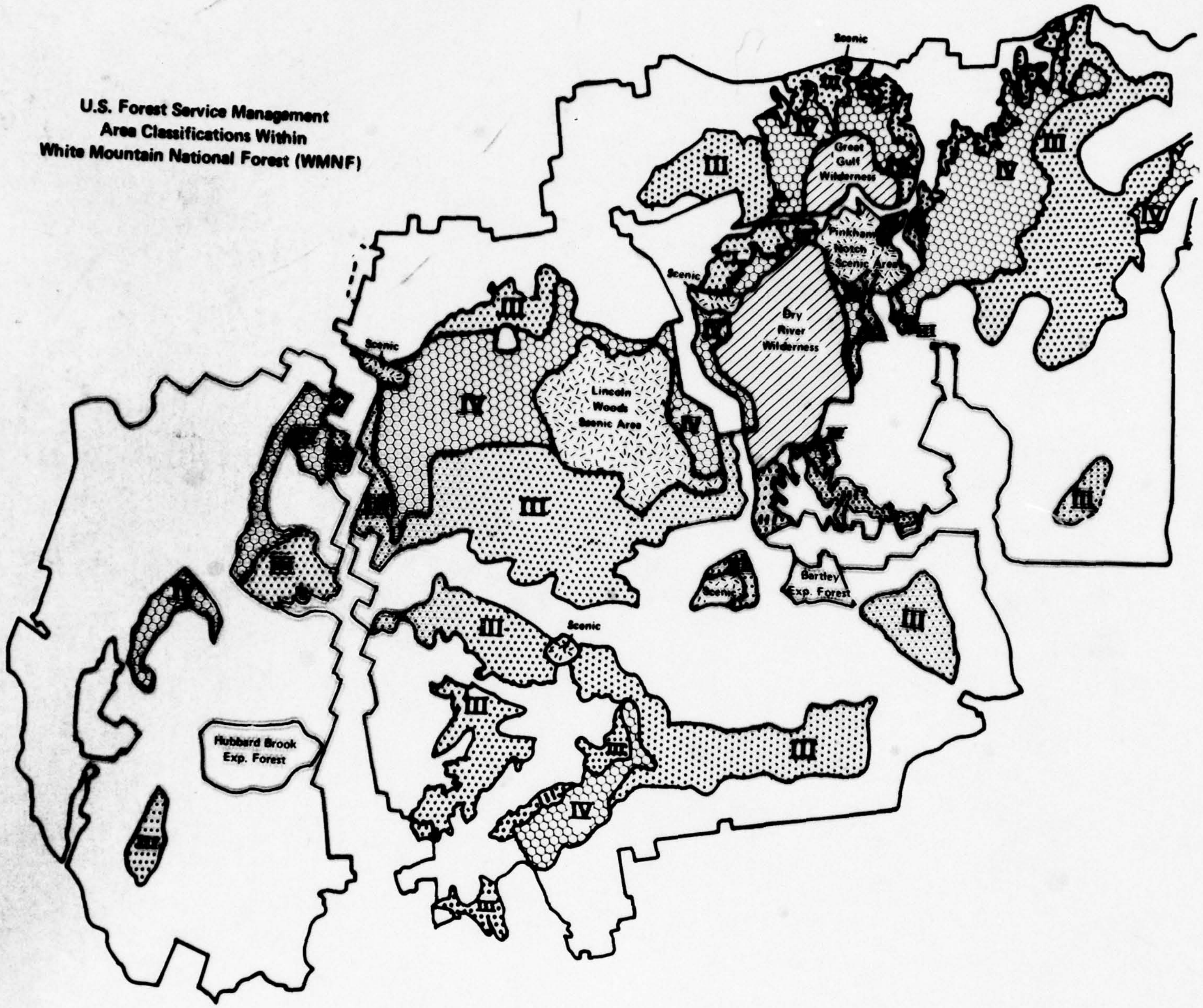
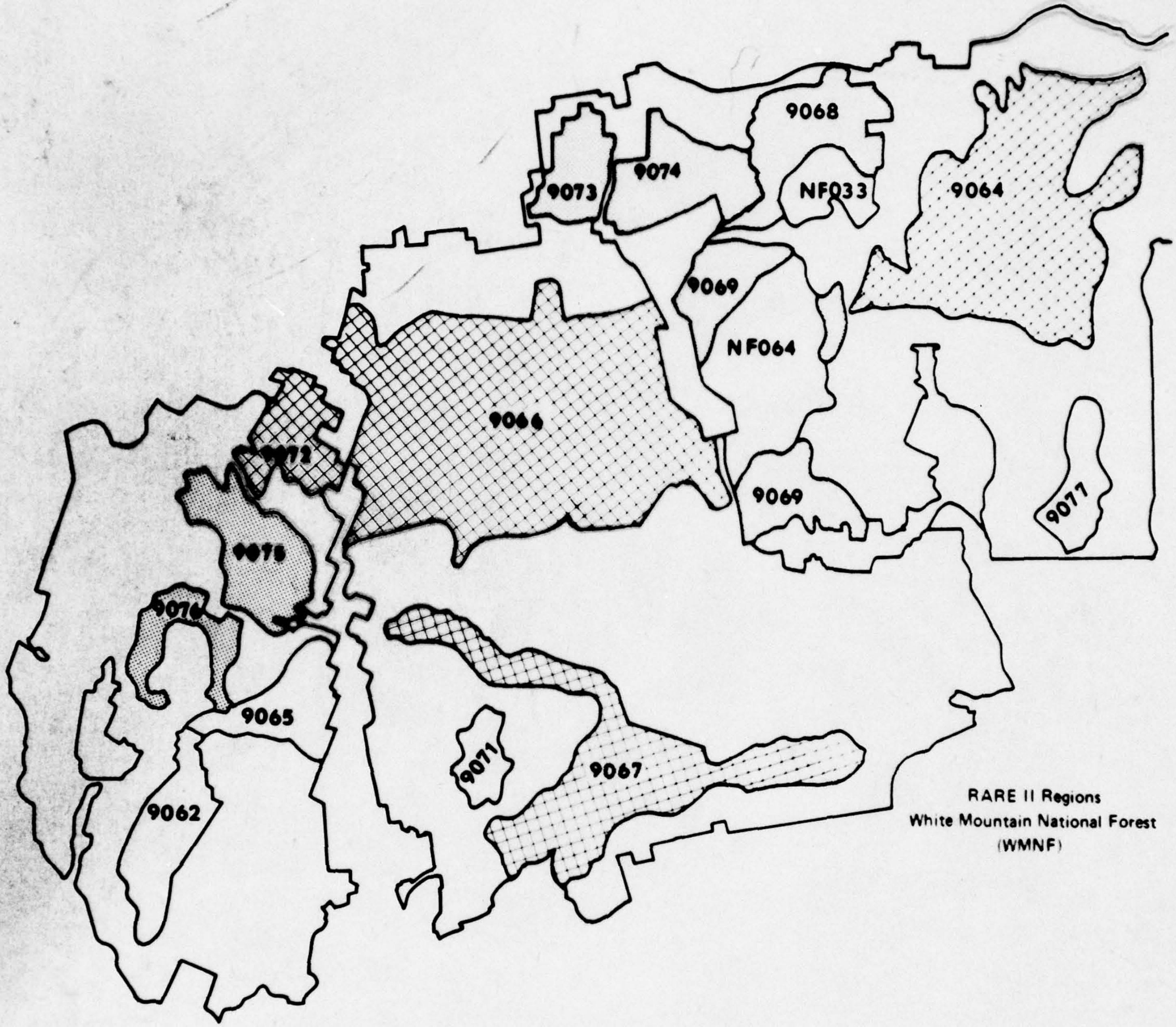


FIGURE A–1
NORTHERN N.H. MAP

(See Figure A–3 Legend)

U.S. Forest Service Management
Area Classifications Within
White Mountain National Forest (WMNF)





RARE II Regions
White Mountain National Forest
(WMNF)

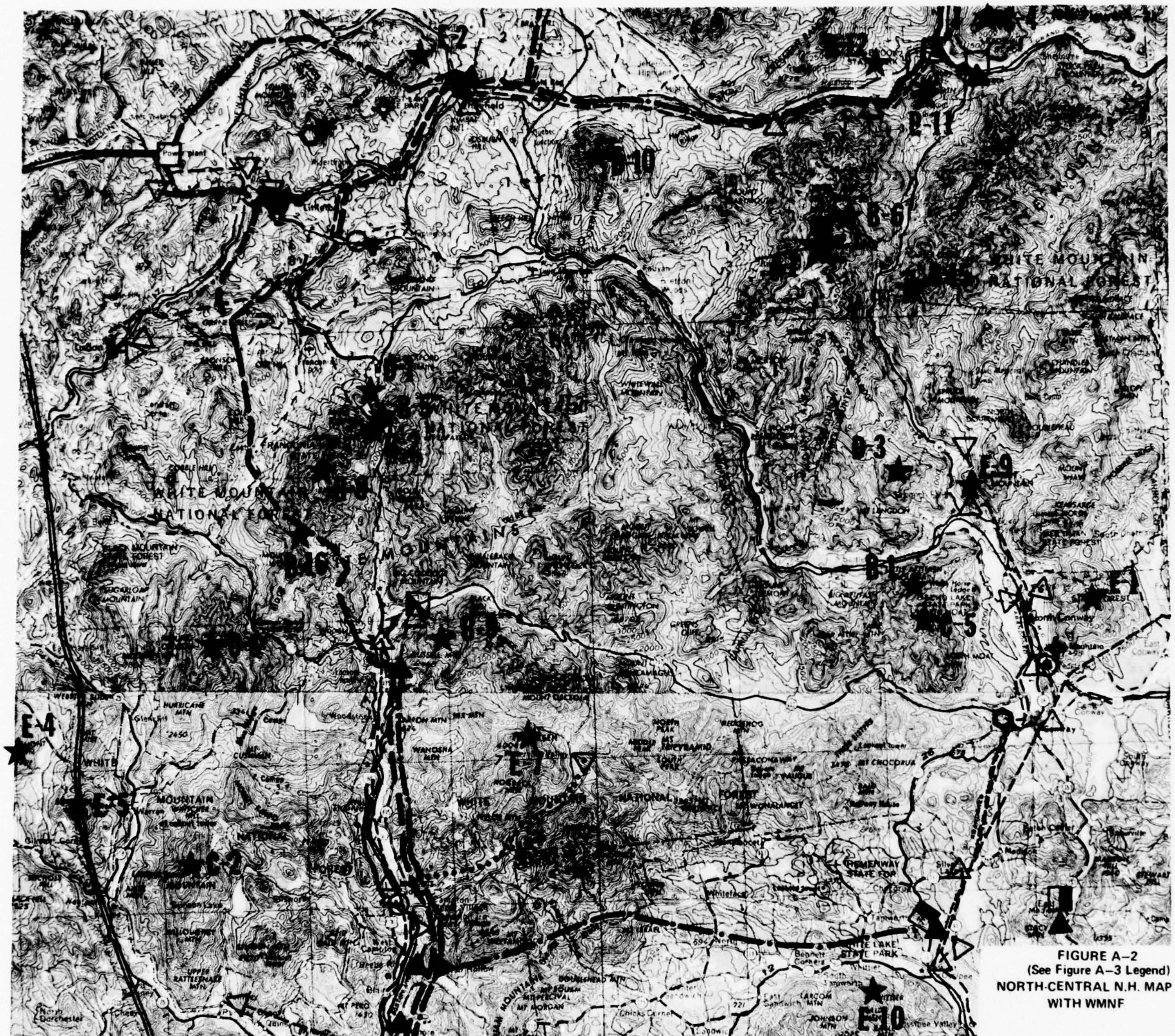
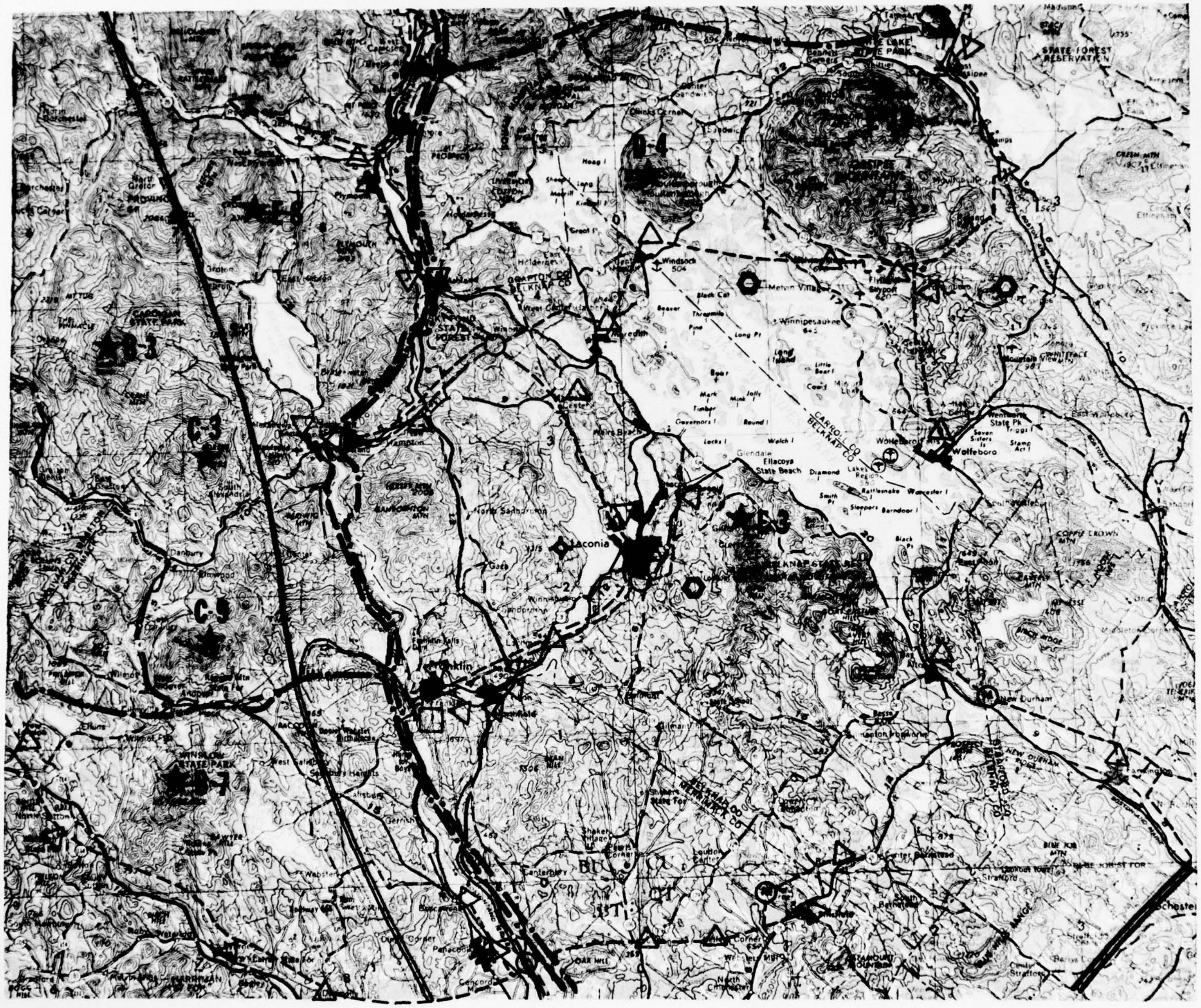


FIGURE A–2
(See Figure A–3 Legend)
NORTH-CENTRAL N.H. MAP
WITH WMNF



Legend:

Utility Grid Legend
345 KV

5 0 5 10 Statue Miles

Utility Grid Legend

- 345 KV
- 230 KV
- 115 KV
- 66 KV
- 33 KV
- 13.2 KV

Statue Miles

5 0 5 10 15 Kilometers

N

- Hydro Generating Station – KVA
- Steam Generating Station – KVA
- Combustion Turbine Generating Station – KVA
- Substation   Customer Owned
- Transmission Substation – KVA
- Switching Station
- Metering Point of COOP

Potential Radio Frequency Interference

- VOR Station
- Non-Directional Radio Beacon
- TV Antenna
- Microwave Repeater Locations

Roadless Area Review & Evaluation (RARE II) Regions Within WMNF (Red Overlay), See Section 5.2.2.3.2

- XX – Wilderness Recommendation (4 Regions)
- 0XX – Further Planning (6 Regions)
- 0XX – Non-Wilderness
- WFXX – Existing Wilderness

Potential Wind Turbine Sites

- A-1 Long Term Anemometry
- B-1 – B-17 On Site Examination of Vegetation Deformation and Measurements
- C-1 – C-9 Aerial Survey Techniques
- D-1 – D-4 Map Interpretation and Remote Observation
- E-1 – E-10 Other Sites Previously Suggested or Proposed in the Literature

U.S. Forest Service Management Area Classification Within WMNF (Blue Overlay), See Section 5.2.2.3.1

- Existing Wilderness Area
- Scenic Area (Special Area)
- IV No Utility Corridors or Antennas
- III No Utility Corridors
- Other Special Area

FIGURE A–3
WIND TURBINE
GENERATOR SITING MAP,
SOUTH CENTRAL, N.H.

2

APPENDIX B

MT. WASHINGTON DATA SUMMARY

The following figures present a summary of the results of an analysis of the hourly wind speed averages from the Mt. Washington Observatory for calendar year 1976. As discussed in the body of this report these data are presented as a benchmark for analyses in Chapters 3 and 4 as well as a potential basis for future analyses.

Figure B-1 presents the results of analyzing the hourly wind speed data measured at the Mount Washington Observatory during 1976. The data, presented as monthly average values, show the wind speed probability distribution of hours per month at a specific wind speed for each increment of wind speed in meters per second. Each plot also presents the monthly average parameters which characterize the Weibull frequency distribution (i.e., the average value for the scale factor C and the shape factor k). The Weibull parameters are also discussed in Chapter 3 (see equation 3-5).

Figure B-2 presents the diurnal available wind power density (P/A) at the Mount Washington summit as estimated by the 1976 hourly wind speed data. The data, shown for each season of the year, can be compared with monthly average data presented in Figure 3-1. It is again clear by Figure B-2 that the predominance of wind energy is the winter months. It is also shown that there is not a strong diurnal variation in general, although it might be said that wind power peaks during the day in the winter and at night during the summer.

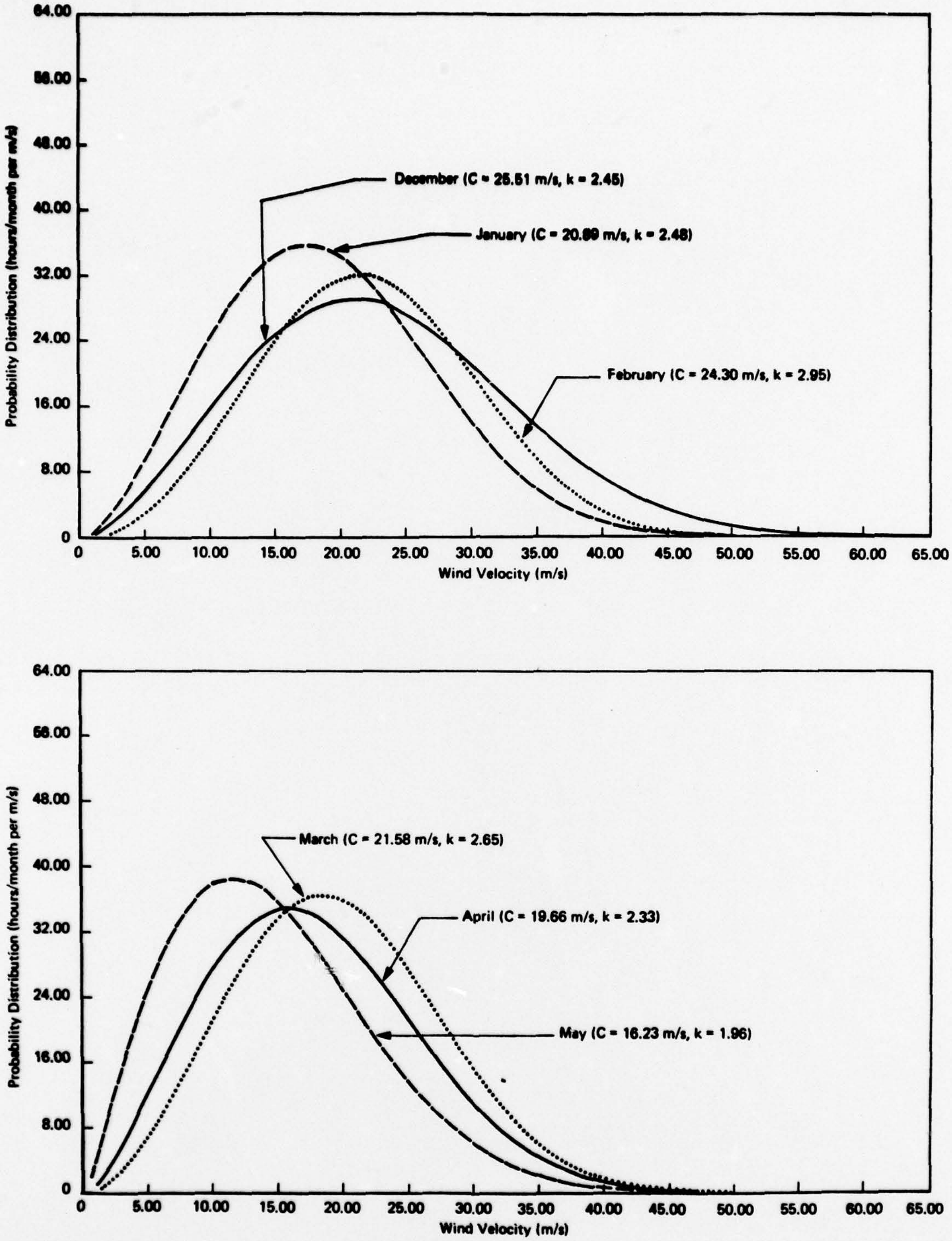
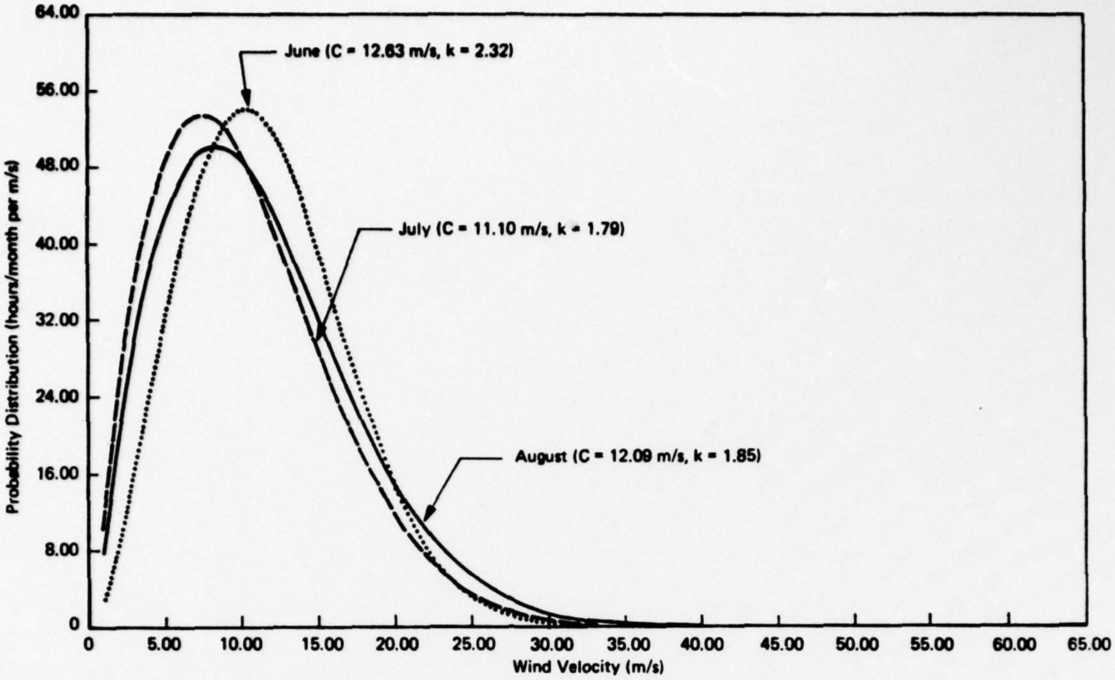


FIGURE B–1 MONTHLY WEIBULL FREQUENCY DISTRIBUTION OF WIND SPEED (HOURS/MONTH/METER PER SECOND) MEASURED AT THE MOUNT WASHINGTON SUMMIT OBSERVATORY DURING 1976



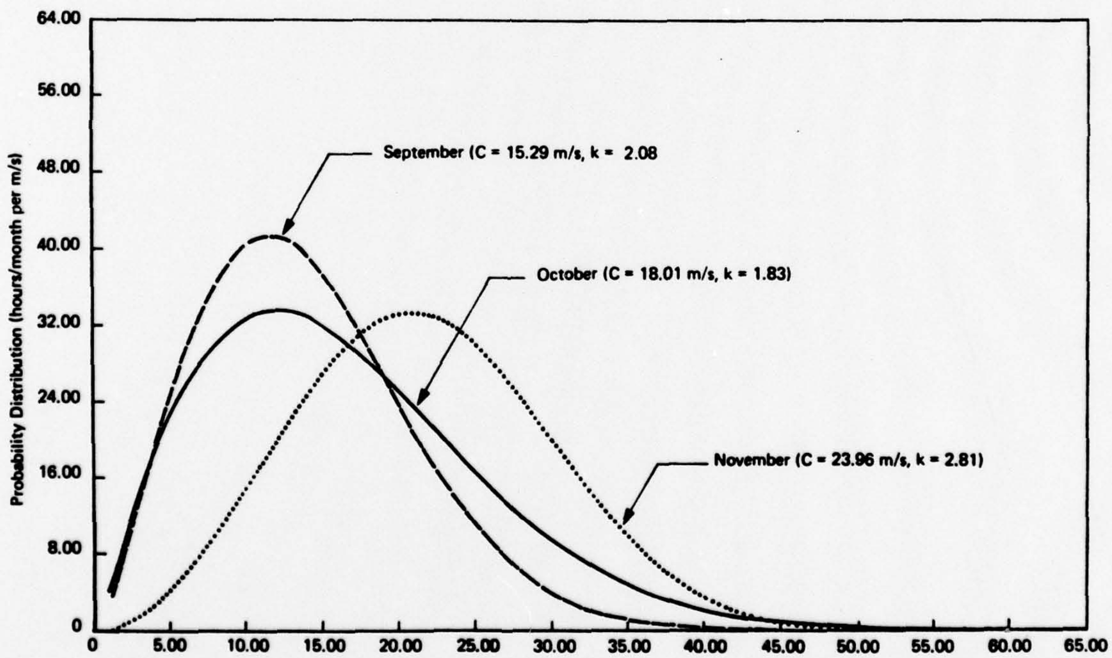


FIGURE B–1 (Continued)

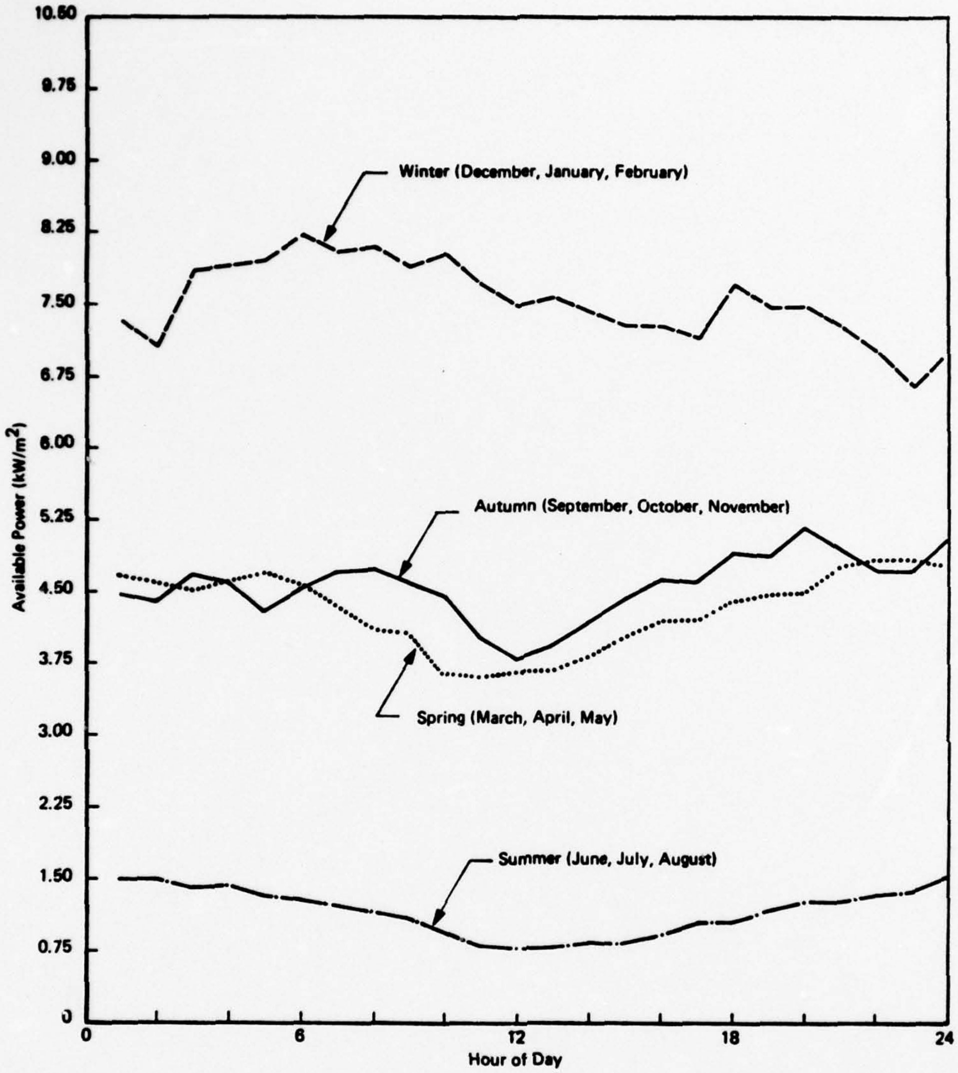


FIGURE B–2 DIURNAL POWER AVAILABILITY BY SEASONS AT MOUNT WASHINGTON SUMMIT BASED ON 1976 HOURLY AVERAGE WIND SPEEDS

APPENDIX C

SUMMARY OF POTENTIAL WT SITES AND THEIR DESCRIPTIONS

The Table C-1 (following) contains a list of each mountain considered in this study and a condensed summary description of each site. The potential sites were broekn into the five following categories in order to facilitate a reader's understanding of the level to which various sites were examined:

- Category A - Long Term Anemometry

  Mt. Washington was the only site studied that had a long term anemometer record.

- Category B - On-site Examination of Vegetation Deformation as an Indicator of Wind Power Potential

  Site visits were made to the 17 sites listed in this category and estimates made of the long term wind power potential by examining trees growing on the mountains.

- Category C - Aerial Survey Techniques

  In order to describe the sites in this category, an aerial examination was made of the site by using a light aircraft. During the flight, efforts were made to examine site access and wind deformed vegetation in a qualitative sense.

- Category D - Map Interpretation and Remote Observation

  Sites in this category were chosen because of their proximity to roads, powerlines, and/or their geographic extent as interpreted by maps. In addition, remote observations of the sites by binoculars, in some cases, provided an estimate of the level of wind deformed vegetation.

- Category E - Other Sites Suggested

  The sites in this category were derived through personal experience and discussions with individuals who are knowledgeable on the subject of wind power potential in New Hampshire.

Table C-1

POTENTIAL WIND TURBINE SITES IN

MOUNTAINS OF NEW HAMPSHIRE

(See Appendix A Maps for Location According to Site Number)

Site Number	Name	Elevation m(ft)	Town	Site Description and Comments
Category A - Long-Term Anemometry				
A-1	Mount Washington	1917 (6288)	Sargent's Purchase	• Long Term Anemometry Records • Annual $\overline{V}_w$ Between 14.7 and 20.5 m/s (33-46 mph) • Excellent exposure, no vegetation at all. • Many reports summarizing wind data. • Limited land available in severely restricted, environmentally sensitive area. Severe icing potential. • Year-round accessibility difficult to maintain.
Category B - On-Site Examination of Vegetation Deformation as Indicator of Wind Power Potential				
B-1	Attitash, Little	767 (2518)	Bartlett	See Tables 3-7 and 3-8.
B-2	Cannon Mtn.	1242 (4077)	Franconia	
B-3	Mt. Cardigan	951 (3121)	Alexandria	
B-4	Dixville Peak	1061 (3482)	Franconia	
B-5	Franconia	~549 (1800)	Franconia	

G = Griggs-Putnam Index for Wind-Flagged Vegetation (see Section 3).

Arthur D Little, Inc.

Table C-1 (continued)

POTENTIAL WIND TURBINE SITES IN

MOUNTAINS OF NEW HAMPSHIRE

(See Appendix A Maps for Location According to Site Number)

Site Number	Name	Elevation m(ft)	Town	Site Description and Comments
Category B - On-Site Examination of Vegetation Deformation as Indicator of Wind Power Potential (continued)				
B-6	Horn - Mt. Washington	1219 (4000)	Sargent's Purchase	See Tables 3-7 and 3-8.
B-7	Mt. Kearsarge	895 (2937)	Wilmot	
B-8	Kinsman Mtn.	1330 (4363)	North Woodstock	
B-9	Loon Mtn.	937 (3072)	Lincoln	
B-10	Mt. Martha	1219 (4000)	Whitefield	
B-11	Pine Mtn.	733 (2404)	Gorham	
B-12	Randolph Hill	457 (1500)	Randolph	
B-13	Mt. Success	1073 (3520)	Berlin	
B-14	Mt. Success Outlook	945 (3100)	Berlin	
B-15	Wildcat Mtn.	1219 (4000)	Bean's Purchase	
B-16	Mt. Wolf	1067 (3500)	Woodstock	
B-17	Crotched Mtn.		Francestown	
Category C - Aerial Survey Techniques				
C-1	Bald Cap	945 (3100)	Berlin	Privately owned clear summit with moderate land availability. Presently not very accessible or near power lines. Good wind energy evidence in tree deformation.
C-2	Carr Mtn.	(1058)(3470)	Wentworth	~2-3 km N-S ridge. Somewhat remote and inaccessible. Lookout tower on summit. Private property.

G = Griggs-Putnam Index for Wind-Flagged Vegetation (see Section 3).

Table C-1 (continued)

POTENTIAL WIND TURBINE SITES IN

MOUNTAINS OF NEW HAMPSHIRE

(See Appendix A Maps for Location According to Site Number)

Category C - Aerial Survey Techniques (continued)

Site Number	Name	Elevation m(ft)	Town	Site Description and Comments
C-3	Forbes Mtn.	688 (2255)	Bristol	Minimal wind deformed vegetation. Access questionable. Private property.
C-4	Mt. Hayes	780 (2555)	Berlin	In Mahoosuc Range. Clear summit of limited extent with ledges upwind of prevailing flow. Suspect high turbulence. Privately owned.
C-5	Moat Mtn.	845 (2800)	Albany	N-S ridge in WMNF. Summit is restricted portion of WMNF. Wind deformed fegetation on ridgeline.
C-6	Moosilauke	1467 (4810)	North Woodstock	High elevation long (~3-4 km) N-S ridge in restricted portion of WMNF. Clear of trees at high elevations. Ice damage evidence in trees.
C-7	North Bald Cap	881 (2890)	Berlin	Clear summit with 1 km wide summit expanse. Lodge downwind of prevailing flow. General topography unsuitable for WT's. Inaccessible. Privately owned.
C-8	Pilot + Pliny Ranges	610-1220 (2000-4000)	Stark & Berlin	Mostly within WMNF except for southern extremity which is somewhat accessible by old logging roads. Moderate land availability on lower (southern) mountain slopes, but not close to powerlines. Wind deformed vegetation evident on upper slopes.
C-9	Ragged Mtn.	683 (2240)	North Andover	Privately owned ski slope with numerous summit trails. Limited land availability. Near power lines and accessible to roads. Minimal evidence of wind deformed vegetation.

G = Griggs-Putnam Index for Wind-Flagged Vegetation (see Section 3).

Table C-1 (continued)

POTENTIAL WIND TURBINE SITES IN

MOUNTAINS OF NEW HAMPSHIRE

(See Appendix A Maps for Location According to Site Number)

Category D - Map Interpretation and Remote Observation				
Site Number	Name	Elevation m(ft)	Town	Site Description and Comments
D-1	Artists Bluff/ Bald Mtn.	735 (2410)	Franconia	Privately owned land of limited extent at NW end of Franconia Notch. Receives outflow of wind from Notch. 1 km from roads and powerlines. Excellent wind speed on ridge indicated by wind deformed vegetation. (See Table 3-8.)
D-2	Mt. Forest	624 (2046)	Berlin	~1 km W of center of Berlin with NW exposure to prevailing flow. Steep cliff to E. No access to summit. Less restricted region of WMNF ~1-2 km W. Possible small WT cluster site. Privately owned.
D-3	Iron Mtn.	828 (2716)	Jackson	In less restricted portion of WMNF <1 km from major highway and powerlines. Limited land available on upper slopes. Evidence of wind deformed trees near top.
D-4	Red Hill	619 (2029)	Moultonborough	Privately owned. Evidence of wind deformed vegetation from easterly flow on west side - may be due to growth reduction on east side of trees caused by prolonged daily shadows. Fire tower on summit. Remote from roads and powerlines. Moderate land availability on E-W ridge.
D-5	Croydon	848 (2781)	Croydon	Long, gently-sloping, clear ridge running NW to SE. Privately owned game preserve with perimeter fence. Fire tower on summit. Near roads but remote from powerlines.

G = Griggs-Putnam Index for Wind-Flagged Vegetation (see Section 3).

Table C-1 (continued)

POTENTIAL WIND TURBINE SITES IN

MOUNTAINS OF NEW HAMPSHIRE

(See Appendix A Maps for Location According to Site Number)

Category E - Other Sites Suggested				
Site Number	Name	Elevation m(ft)	Town	Site Description and Comments
E-1	Black Cap Mtn.	610 (2000)	Kearsarge/North Conway	Privately owned. Bare summit. Possible access by paved Hurricane Mtn. road.
E-2	Dalton Mtn.	610 (2000)	Dalton	Privately owned. NE-SW ridge along Conn. River. Access road and powerlines nearby.
E-3	Gunstock Mtn.	683 (2240)	Gilford	Privately owned. Ski slope and trails.
E-4	Piermont Mtn.	830 (2721)	Piermont	Privately owned. Near roads and major powerline (i.e., 1-2 km) through state.
E-5	Sentinel Mtn.	(2201)	Warren	Borders less restricted portion of WMNF near roads (1-2 km). Major powerline passes near summit.
E-6	Sugarloof Mtn.	1129 (3701)	North Stratford	Privately owned. With fire tower and access road. Remote from powerlines.
E-7	Mt. Tecumseh	1221 (4004)	Waterville	Higher elevations in restricted portion of WMNF. Waterville Valley ski area on portion of mountain. Good access road to base. Existing powerlines.

G = Griggs-Putnam Index for Wind-Flagged Vegetation (see Section 3).

Table C-1 (continued)

POTENTIAL WIND TURBINE SITES IN

MOUNTAINS OF NEW HAMPSHIRE

(See Appendix A Maps for Location According to Site Number)

Category E - Other Sites Suggested (continued)				
Site Number	Name	Elevation m(ft)	Town	Site Description and Comments
E-8	Tenney Mtn.	704 (2310)	Plymouth	Privately owned. Ski slope on mountain. 2-3 km to roads and powerlines.
E-9	Thorn Hill	445 (1460)	Jackson	Privately owned land with many homes on high hillside. Access road and powerlines nearby.
E-10	Mt. Whittier	672 (2205)	Ossipee	Privately owned. Ski slopes on NE side. Large expanse of land in Ossipee Mountains to S and W. Near road and powerlines.

G = Griggs-Putnam Index for Wind-Flagged Vegetation (see Section 3).

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